State of California

AIR RESOURCES BOARD

SUPPLEMENT

TO

STATIONARY SOURCE TEST METHODS

———

Volume 1

———

Methods for Determining Compliance

with

District Nonvehicular (Stationary Source)

Emission Standards

Stationary Source Division

APPENDIX A

ADDITIONAL INFORMATION FOR USING ARB MODEL
STATIONARY SOURCE TEST METHODS

TABLE OF CONTENTS

CHAPTER I

INTRODUCTION

AIR RESOURCES BOARD'S METHODS
FOR EMISSION SAMPLING AND SAMPLE ANALYSIS

The information presented here deals with the Air Resources Board's (ARB's) sampling and analysis methods for emissions from stationary sources. This manual covers ARB Methods for

1)   sample and velocity traverse
2)   velocity and flow rate
3)   carbon dioxide, excess air and molecular weight
4)   moisture
5)   particulate matter
6)   sulfur dioxide
7)   nitrogen oxides
8)   sulfuric acid mist and sulfur dioxide

For hydrocarbon emissions, a method devised by the Air Resources Board (ARB) staff and the State Department of Health is presented.

Where applicable, the ARB methods are similar to the EPA *methods* published in the following issue of the Federal Register:

~~December 23, 1971~~ – Methods 1 through 9 Promulgated
August 18, 1977

ARB staff has had to modify the EPA methods for use in determining compliance with California APCD rules and regulations and for use on certain types of sources. Such modifications are included in this manual.

The EPA methods upon which the ARB methods are based were promulgated for determining compliance with the EPA New Source Performance Standards, and are not required for determining compliance of existing sources with APCD rules and regulations. EPA has indicated that an APCD can use its own test methods for determining compliance of existing sources with APCD rules. However, EPA has also indicated that the EPA methods can be required as the referee methods in disputes over compliance that involve EPA. Therefore, regardless of the methods customarily used by an APCD, the APCD personnel should be familiar with the EPA methods.

CHAPTER II

PRELIMINARY OPERATIONS

1.   INTRODUCTION

Pre-source test planning should be conducted once the decision has been made to test emissions from a source. These plans help insure that the test is conducted safely and accurately. The preliminary operations include, but are not limited to, the following:

i)   Inspection of the source;
ii)   Planning the test; and
iii)   Preparation for the test.

2.   INSPECTION OF THE SOURCE

Prior to the test an inspection should be made of the source. This inspection is to determine those operating conditions of the plant necessary to plan the testing, and to either make certain that the existing platforms and ports are satisfactory or to obtain sufficient information so that the source operator may be advised on what he must do to prepare for the test.

The inspection is best conducted with the use of an inspection form which provides for all of the routine requirements, such as persons to contact, flow rates, process weights, stack diameters, stack heights and air pollution problems. The form should provide sufficient space to make a sketch of the process and of the stack. The inspection form used by the ARB staff is shown in Appendix II-1.

During the test the plant should be operating at the maximum load at which it will be operated. Otherwise, the permit-to-operate may have to contain a condition that limits the plant to the operating load that prevailed during the test. Another test at the maximum operating load may be required to remove this condition from the permit. This consideration should be discussed with the source operator during the inspection and an agreement reached on the operating load during the test.

Existing platforms must be carefully inspected to determine if they are safe and if they meet the needs of the source test. The platform should be strong and rigid. The platform should be at least 36 inches wide, with a railing 42 inches high. An intermediate rail between the top rail and the platform floor is highly desirable, since some work is done in a crouched position and it is possible for a person to back over the edge of the platform floor and under the top railing. The platform should have a toeboard which will prevent stepping off the edge and also reduces the danger of tools or equipment falling over the edge. The position of

the ports should be such that there will be no interference of the test equipment with the railing. During the testing, the sample box which is suspended on the end of the probe, must clear the railing as the probe traverses the stack.

The access to the platform should be safe. If equipment must be brought up to the platform via the platform access, then the access must be inspected to make certain that this can be done with the people and equipment available.

If the existing platforms or access do not meet the safety requirements of the State or OSHA, then the source operator must be advised of the changes he must make before the test is conducted. If the existing ports are not satisfactory, either it may be possible to make an adaptor to suit the sampling equipment, or it may be necessary to require the source operator to install new ports. If changes are made, there must be a reinspection to ensure that the changes are satisfactory.

If sampling platforms and ports must be installed, the ARB staff uses the specification sheet shown in Appendix II-2. This sheet is a sketch that gives the requirements of the platforms and ports. Note that no specification is given for the size of the members in the platform other than that the platform conforms to the requirements of the California State Industrial Safety Orders and the Uniform Building Code. The Uniform Building Code is incorporated into the building code of most municipalities. This code governs the strengths of the members in the platform and access, and if it is followed there should be no concern about the strength of the platform.

The strength of the stack must be considered because of the eccentric load applied to the stack by the addition of the platform. The wall thickness of the stack should be sufficient to withstand this additional load, or the platform should be supported independently from the stack. The Uniform Building Code requires that the stack withstand the load if the platform is supported by the stack. Make certain that during the test, no abnormal load is applied to the platform.

The sketch also requires that the platform and access conform to the California State Industrial Safety Orders. These orders require adequate width, rail heights, and toe boards. APCD officials should become familiar with these orders for their own protection.

Inspect the platforms, access and ports prior to the test to ensure that the installation has been done satisfactorily.

Use detector tubes and/or portable analyzers to determine the concentrations of hazardous pollutants that may exist within the source test sampling area. This precaution will help insure that source test personnel are not exposed to a dangerous working environment.

The source operator must provide 110V, 60 Hertz, single phase electrical current. The current needs of most testing equipment is not high, so extensions of a reasonable length may be used. Caution must be observed when using portable 110V generators. The time indicators in some instruments depend upon an accurate frequency of the supply current. With such instruments, if the supply current frequency is for example, 66 Hertz rather than 60, the actual duration of the test will be 10% short of the planned duration. Later calculations would show a false error in the isokinetic ratio.

When the site is initially inspected, consider the way in which the source test van can be located relative to the stack. If the van can be located close to the stack, much trouble and effort can be saved during the test.

Photographs of the stack and operation can be helpful in planning the test and in documentation. Obtain the permission of the owner before taking photographs.

3.   PLANNING THE TEST

The best method of planning for the test is to prepare a writeup sheet for the test with a check-list of items to be done.

If sampling platforms and ports must be installed, the source operator must be written and informed of the requirements for the sampling platform and ports.

Personnel must be assigned to the test and informed of their duties. The State has found that a minimum of two people are required to conduct the simplest particulate test, and it is preferable to have three. One person should be assigned to the console and one person to the sample probe. Another person is desirable for support activities such as replacing ice, delivering sample trains as required and properly identifying samples. Frequently other samples are taken during the particulate test, and man-time must be provided for these. Man-time should also be provided to monitor the process in order to obtain process weight and other process variables and to ensure that the plant is operating uniformly during the test at the desired capacity.

The weather must be considered in planning the test. Rain or snow may render conditions unsafe that would otherwise be safe. The possibility of this must be determined during the first inspection of the source. In addition, the test equipment is generally not weatherproof. Special precautions should be considered to prevent electrical shocks to the test personnel and to prevent damage to the equipment by weather. As a special precaution in all kinds of weather, ground the probe itself electrically during sampling.

The test may require some special equipment such as lifting equipment. This must be arranged for. In addition, it is sometimes necessary to provide

extensions on exhaust stacks in order to provide sufficient stack length for a valid test. The source operator must be advised of the extra requirements.

Another important function before the test is to arrange for analysis of the samples.

The test itself requires routine forms and sometimes special forms for the process. These must be provided beforehand.

4.   PREPARATION FOR EMISSION SAMPLING

A checklist of the equipment should be prepared and checked off as equipment is stored in the source test van. A discussion of the equipment required for each type of test follows in later chapters.

Sample trains should be prepared in the workshop prior to leaving for the test. This is more efficient and will save valuable time on the test.

The check-list should include the reagents required. These will have to be obtained from the laboratory prior to the test.

5.   SUMMARY

The successful source test requires careful formalized planning. The overriding consideration in planning is that conditions be safe. A source test should not be undertaken if conditions are not safe.

The planning should include:

1.   Pre-test inspection of the source
2.   Re-inspection if necessary
3.   Safe and adequate sampling platforms and access
4.   Suitable ports
5.   Electrical outlets – 110V, 60 Hertz
6.   A project write-up sheet
7.   Assignment of enough people
8.   Procurement of adequate equipment
9.   An equipment check-off sheet
10.   Preparation of necessary test and process data forms
11.   Arrangements for analysis of samples.

APPENDIX II

1.   ENGINEERING INVESTIGATION REPORT FORM

2.   PLATFORM AND PORT SPECIFICATION SHEET

STATE OF CALIFORNIA AIR RESOURCES BOARD

Engineering Investigation Report

COUNTY	FILE NO.	DATE OF VISIT	INVESTIGATED BY

1. ACTION

☐ Local authorities contacted ☐ Suspected source of pollution toured ☐

☐ Problem area surveyed ☐ Possible sampling sites located ☐

☐ Complaintant interviewed   Time of visit _____ to _____ ☐

2. RECOMMENDATIONS

☐ No air pollution problem

☐ Further investigation (explain)

☐ Information required from

☐ Stack test (if recommended, complete the following)

    a. Accessibility of sampling ports _____

    b. Straight stack diameters upstream and downstream of ports _____

    c. Stack diameter (ft.) _____ e. Velocity of flue gas (FPM) _____

    d. Moisture content (%) _____ f. Temperature of flue gas _____

3. COUNTY OFFICIAL CONTACTED
Name and address (include title)

4. SUSPECTED SOURCE OF AIR POLLUTION

Name and address	Production rate
	Tons/year _____ Tons/day _____
	Operating schedule
	Days/week _____ Hours/day _____

5. COMPANY OFFICIALS INTERVIEWED

name (include title)	Company official to contact

6. SPECIFIC COMPLAINT (PARTICULATE, ODOR, FREQUENCY, EFFECTS, ETC.)

_____
_____
_____
_____
_____
_____
_____
_____
_____

7. ATTACHMENTS

☐ Field notes   ☐ Photographs   ☐ Lab reports   ☐ Related correspondence

8. SOURCE PROCESS DESCRIPTION (MATERIALS USED, AMOUNTS, ETC.)

_____
_____
_____
_____

9. SOURCE POLLUTION CONTROL EQUIPMENT

Type _____   Manufacturer _____

Capacity _____   Efficiency _____

_____ _____   _____ _____

 MONITORING PROGRAM

_____
_____
_____
_____

10. OBSERVATIONS

_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

11. ADDITIONAL INFORMATION (SKETCHS, OTHER POSSIBLE AIR POLLUTION SOURCES, ETC.)

APPENDIX II-2

PLATFORM AND PORT SPECIFICATION SHEET

OBSTRUCTION

90°

14' MINIMUM CLEARANCE FROM SAMPLING PORT

2 diameters (ideal) 1/2 diameters (min.)

SAMPLING PORTS

3" NPT COUPLING. WELD TO STACK. CUT HOLE IN STACK TO I.D. OF COUPLING. INSTALL 3" PIPE PLUG.

$14\frac{1}{2}$"

42"

FLOOR OF PLATFORM

8 diameters (ideal) 2 diameters (min.)

4'

NOTES:

1. PROVIDE PLATFORM EXTENDING TO A MINIMUM OF 3' ON EACH SIDE OF EACH SAMPLING PORT.

2. PLATFORM & ACCESS TO PLATFORM SHALL CONFORM TO CALIFORNIA INDUSTRIAL SAFETY ORDERS & UNIFORM BUILDING CODE.

4. If the stack diameter is too large to traverse from one port, 4 sampling ports at 90° apart may be used to traverse the stack. This avoids using a longer probe which may cause sagging (a non-perpendicular arrangement).

3. LOCATE PORTS ON WINDWARD SIDE IF POSSIBLE.

CHAPTER III

DETERMINATION OF VELOCITY AND FLOW RATE

1. INTRODUCTION

The rate of emission to atmosphere of an air pollutant from a source is the product of the fractional pollutant concentration in the stack gas and the total flow rate of the stack gas that is emitted to atmosphere. Methods for determining pollutant concentration are discussed in the following chapters. This chapter covers determining the velocity and flow rate of the stack gas.

The flow rate of stack gas to atmosphere from a stack is the product of the average gas velocity in the stack and the cross-sectional area of the stack. The area of the stack is determined simply from its internal dimensions. Determining average velocity requires accurate field measurements with the proper equipment. Determining the flow rate generally involves recalculating field measurements to standard conditions and the dry basis, as required by APCD and ARB regulations in determining compliance. The theory involved in velocity determination, the flow rate calculations, and the technique and equipment for velocity determination are discussed below.

2. DEVELOPMENT OF USEABLE EQUATIONS

2.1 Stack Gas Velocity

The fundamental equation of motion for steady state fluid flow is Bernoulli's Equation:

$$\frac{P_1}{w} + Z_1 + \frac{U_1^2}{2g} = \frac{P_2}{w} + Z_2 + \frac{U_2^2}{2g}$$

This equation states the law of conservation of energy, showing that the summation of energies along a streamline at one point in a fluid flow system (subscript 1) is equal to the summation of energies along the streamline at another point (subscript 2). If we apply any consistent units to the symbols in the equation, we see that each term of the equation is stated as pressure head of the fluid. For example, if we set

P   =   Pressure, pounds per square foot (lbs/ft^2)
W   =   Density, pounds per cubic foot (lbs/ft.^{3})
Z   =   Elevation above a datum, feet (ft.)
U   =   Fluid velocity, feet per second (ft./sec.)
g   =   Gravity constant (32.2 ft/sec.^{2})

then

$\dfrac{p}{w}$ = Head due to pressure, ft.

Z = Head due to elevation, ft.

$\dfrac{U_2}{2g}$ = Head due to velocity, ft.

This fundamental equation assumes an incompressible, frictionless fluid. These assumptions do not introduce significant errors in air pollution emission sampling, since we are dealing with gases at low pressure.

For practical use in determining velocity in a stack, Bernoulli's Equation can be reduced. Since differences in elevation are small, elevation head (Z) can be neglected. Also, consider that pressure heads are measured by inserting into the stack a pitot tube, which is attached outside the stack to a manometer as shown in Figure III-1 for an "S" type pitot. Of the two points in the fluid flow system, set point 1 (subscript 1) in the gas stream in the stack, and set point 2 (subscript 2) in that opening of the pitot tube that will directly face the gas stream. Gas at point 2 will have zero velocity, such that

$$\frac{U_2{}^2}{2g} = 0$$

Therefore, the pressure head P_2, is the total head, equal to pressure head plus velocity head. Equation (3-1) now becomes

$$\frac{P_1}{w} + \frac{U_1{}^2}{2g} = \frac{P_2}{w} \tag{3-2}$$

or

$$U_1 = \sqrt{\frac{2g\left(P_2 - P_1\right)}{w}} \tag{3-3}$$

Now, one lb-mole of gas occupies 385 ft.[3] at 68°F (528°R) and 29.92 in Hg. (2116.8 lbs/ft.[2]). Therefore,

$$w_{std} = \frac{M}{385} \tag{3-4}$$

"S" TYPE PITOT TUBE

THERMOCOUPLE

FLEXIBLE TUBING

TEMPERATURE
INDICATOR
(POTENTIOMETER)

INCLINED
MANOMETER
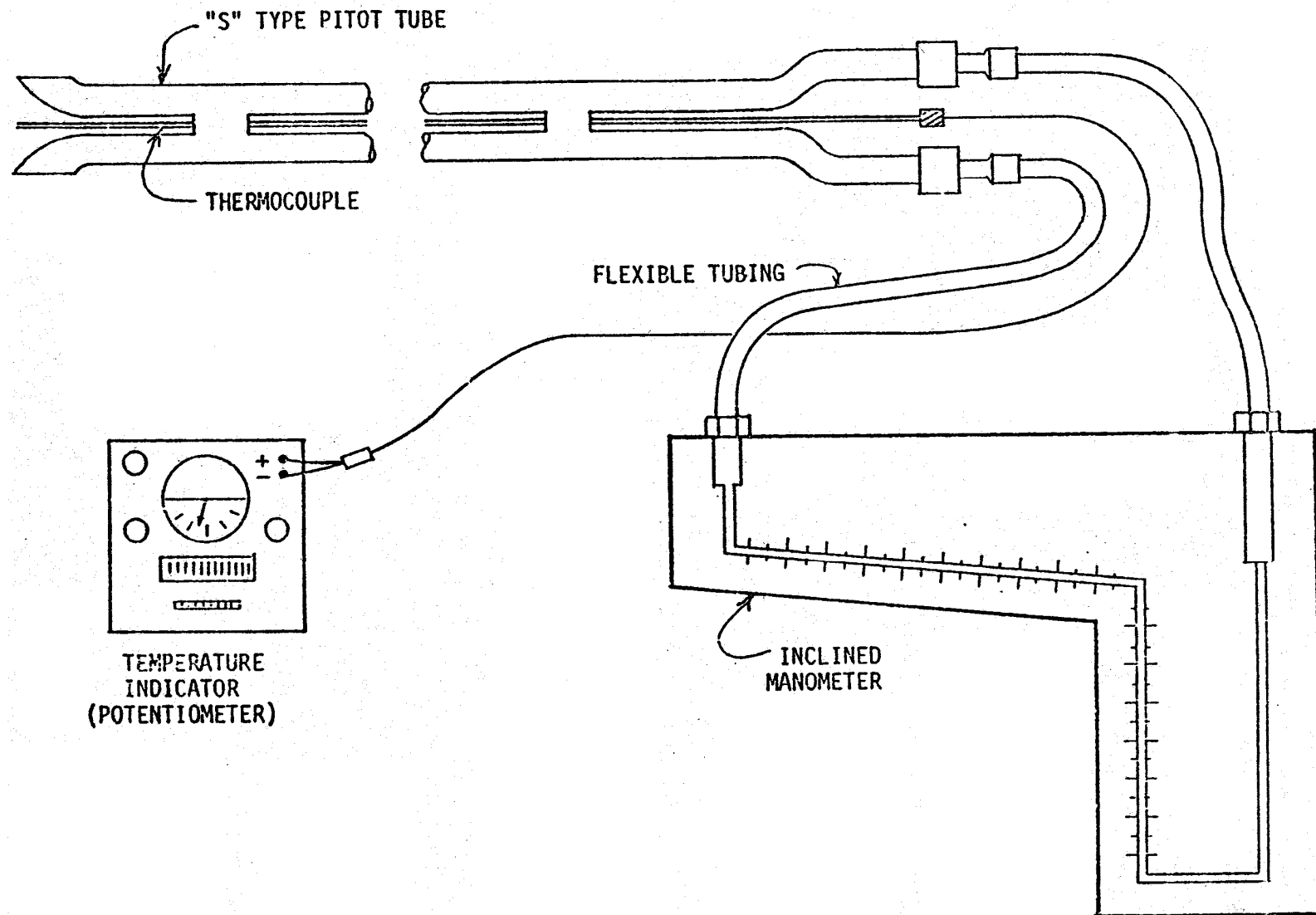
FIGURE III-1: VELOCITY PROBE ASSEMBLY

where

W_{std} = Density of the gas at standard conditions

M = Molecular weight of the gas.

Applying Charles and Boyles Laws to convert to stack conditions, we have

$$w_s = \frac{M_s}{385} \text{ x } \frac{528}{T_s} \text{ x } \frac{P_2}{2116.8}$$ (3-5)

where

M_s = Molecular weight of stack gas, lbs.

T_s = Absolute temperature of stack gas, °R

P_2 = Absolute pressure of stack gas, lbs/ft.^{2}

P_2 in equation (3-5) and $(P_2 - P_1)$ in equation (3-3) are in terms of lbs/ft.^{2} In emission sampling, the absolute pressure of the stack gas, P_s in measured in inches of mercury. The term

$$\frac{P_2}{2116.8}$$

in equation (3-5) is the stack pressure divided by the standard pressure and the units (lbs/ft.^{2}) cancel. Therefore, we restate the term as

$$\frac{P_s}{29.92}$$

where both numerator and denominator are in inches of mercury. Also, we measure $(P_2 - P_1)$ in inches of water with a pitot tube and manometer. A cubic foot of water weighs 62.32 lbs at 68°F and a one-inch column of water on a square foot of surface exerts pressure equal to

$$\frac{62.32}{12} \text{ lbs/ft.}^2$$

Therefore, $(P_2 - P_1)$ can be converted according to the equation

$$\left(P_2 - P_1\right) = \Delta P \frac{(62.32)}{12}$$ (3-6)

Where ΔP is the differential head in inches of water. Substituting from equations (3-5) and (3-6) into equation (3-3), we have

$$U_1 = \frac{\sqrt{2 \times 32.2 \times 62.32 \times 385 \times 29.92 \times \Delta P \times T_s}}{12 \times 528 \times P_s \times M_s} \qquad (3\text{-}7)$$

or

$$U_1 = 85.39 \sqrt{\Delta P} \sqrt{\frac{T_s}{M_s P_s}} \qquad (3\text{-}8)$$

A "standard" pitot tube generally gives readings for ΔP that are within 1% of true readings. However, this type of pitot is bulky and can easily clog with particulate matter. Therefore, its use is not practical in many sampling situations. The "S" type pitot (Figure III-1) is relatively smaller and less subject to clogging. It is recommended for use in emission sampling. However, it gives consistently high readings, and a correction factor that is generally between 0.8 and 0.9 must be used. Applying this factor to equation (3-8) and using proper terminology for emission sampling, we have

$$U_s = 85.39\, C_p \sqrt{\Delta P}\ \text{avg.} \sqrt{\frac{T_s\ \text{avg}}{P_s \times M_s}} \qquad (3\text{-}9)$$

where
   U_s = Average stack gas velocity, ft/sec.
   C_p = Pitot correction factor, if unknown use
        = 1.0 for "standard" pitot
        = 0.855 for "S" type pitot[*]
$\sqrt{\Delta P}$ avg = Root average velocity head, (inches $H_2O)^{1/2}$
   T_s avg = Average absolute stack gas temperature, ℝ
   P_s = Absolute stack gas pressure, inches Hg.
   M_s = Molecular weight of stack gas, lbs.

This is the equation used to calculate average stack gas velocity in emission sampling and is shown on the velocity and flow rate calculation sheet, Appendix III-1.

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[*] The method for calibrating pitot tubes is described in Appendix III-5.

2.2   Actual Flow Rate

The flow rate of gas in a stack is determined from the equation

$$Q_a = 60\, U_s\, A \qquad\qquad (3\text{-}10)$$

where
  Q_a =   Actual gas flow rate, ft^3/min.
  U_s =   Average stack gas velocity from equation (3-9), ft/sec.
  A =   Internal cross-sectional area of stack, ft.^{2}

This equation gives the flow rate in terms of actual cubic feet per minute (ACFM). The flow rate is at stack conditions and includes whatever moisture is present. ARB regulations and those of California APCDs require reporting flows at dry standard conditions in cubic feet per minute (SDCFM). Recalculating to these conditions is discussed below.

2.3   Flow Rate at Standard Conditions

California APCD rules generally define standard conditions as 60°F and 14.7 pounds per square inch absolute (or 29.92 inches Hg). The National Standards of Performance for New Stationary Sources established by ARB define standard conditions as 528°R and 29.92 inches Hg.

A given gas volume is directly proportional to the temperature and inversely proportional to the pressure. Therefore, for any Q_a from equation (3-10), if the pressure is held constant and the temperature is changed to standard, we have

$$Q_a = \frac{Q_a\, T_{std}}{T_s} \qquad\qquad (3\text{-}11)$$

If the temperature is now held constant and the pressure is changed to standard conditions we have,

$$Q_{std} = \frac{Q_a\, P_s}{P_{std}} \qquad\qquad (3\text{-}12)$$

Substituting for Q_a we have

$$Q_{std} = \frac{T_{std}\, P_s\, Q}{T_s\, P_{std}}$$ (3-13)

For California APCDs having standard conditions at 68°F and 29.92 in Hg., the conversion equation is

$$Q_{std} = \frac{528\, P_s\, Q_a}{29.92\, T_s} = 17.65\, \frac{P_s\, Q_a}{T_s}$$ (3-14)

The general equation for gas flow rate at standard conditions and wet basis recalculated from actual conditions (equation 3-8) is

$$Q_{std} = 60\, U_s\, A\, \frac{T_{std}\, P_s}{T_s\, avg\, P_{std}}$$ (3-15)

where
Q_{std} is in terms of standard cubic feet per minute (SCFM).

2.4   Flow Rate, Dry Basis and Standard Conditions

Volume on the dry basis equals volume on the wet basis minus the volume of water vapor:

$$V_{dry} = V_{wet} - V_{water\ vapor}$$ (3-16)

The amount of water in the stack gas is routinely determined during emission sampling as discussed in Chapter IV. To convert the flow rate in equation (3-16) to the dry basis we apply

Conversion factor = $(1 - B_{wo})$ (3-17)

where
B_{wo} is the volume fraction of water vapor in the stack gas.

We now have

$$Q_s = 60\left(1 - B_{wo}\right) U_s\, A\, \frac{T_{std}\, P_s}{T_s\, P_{std}}$$ (3-18)

where

Q_s	=	Flow rate, dry standard cubic feet per minute (DSCFM)
B_{wo}	=	Volume fraction of water vapor in the gas
U_s	=	Average stack gas velocity, ft/sec.
A	=	Internal cross-sectional area of stack, ft.^{2}
T_s	=	Average absolute stack gas temperature, °R
P_s	=	Absolute stack gas pressure, in Hg.
T_{std}	=	Standard absolute gas temperature, °R
P_{std}	=	Standard absolute pressure, in. Hg.

This is the equation used in emission sampling, and is shown on the velocity and flow rate calculation sheet, Appendix III-1.

3. FIELD MEASUREMENTS

The use of equation (3-18) for gas flow rate requires field measurements to determine the stack cross-sectional area and the gas velocity, temperature and pressure. Determining the stack area should require no further explanation. Determining the gas velocity, as seen from equation (3-9) involves measurements of velocity head, temperature, pressure and molecular weight.

3.1 Velocity

Head (ΔP) and temperature (T_s avg)

3.1.1 Equipment

The typical field equipment is shown in Figure III-1, including the following.

- "S" type pitot tube of proper length
- Inclined manometer, 0-10 inches H_2O full scale, in increment of 0.01 inch H_2O
- Thermocouple
- Potentiometer, direct reading in °F
- Aneroid Barometer

A U-tube manometer of the proper scale may be used for higher velocity heads. Other methods for measuring velocity directly, or velocity head, ad for measuring differential pressure are given in Appendices III-3 and III-4.

One 5-foot and one 10-foot pitot tube will cover almost all of the situations encountered by an APCD.

Chromel-alumel thermocouples with the proper potentiometers are readily available from many sources and are recommended. Iron-constantan thermocouples have advantages over chromel-alumel, but the proper direct reading potentiometers are not generally available.

3.1.2 Traverse Points

Principle. Ts aid in the representative measurement of pollutant emissions and/or total volumetric flow rate from a stationary source, a measurement site where the effluent stream is flowing in a known direction is selected, and the cross-section of the stack is divided into a number of equal areas. A traverse point is then located within each of these equal areas.

Applicability. This method is applicable to flowing gas streams in ducts, stacks, and flues. The method cannot be used when:

i)	flow is cyclonic or swirling (see Section 3.1.3),
ii)	a stack is smaller than about 0.30 meter (12 in) in diameter, or 0.071 m^2 (133in^2) in cross-sectional area, or
iii)	the measurement site is less than two stack or duct diameters downstream or less than a half diameter upstream from a flow disturbance.

The requirements of this method must be considered before construction of a new facility from which emissions will be measured; failure to do so may require subsequent alterations to the stack or deviation from the standard procedure. Cases involving variants are subject to the approval by the Executive Officer, Air Resources Board.

The velocity in a stack is not uniform from point to point across the stack. It is, therefore, necessary to traverse the stack with the pitot and measure the velocity head at several points. The minimum number of traverse points (12 points) is required if the sampling point is at least 2 stack diameters upstream and 8 stack diameters downstream of any disturbance of the gas stream, such as bends, contractions, expansions, visible flame, or stack outlet to atmosphere.

Number of Duct Diameters Downstream from Sampling Point * (A)

For stacks having diameters less than 2 feet, multiply the values obtained from this graph by 0.67

* To Point of Any Type of Disturbance (Bend, Expansion, Contraction, Etc.)

Number of Duct Diameters Upstream from Sampling Point * (B)
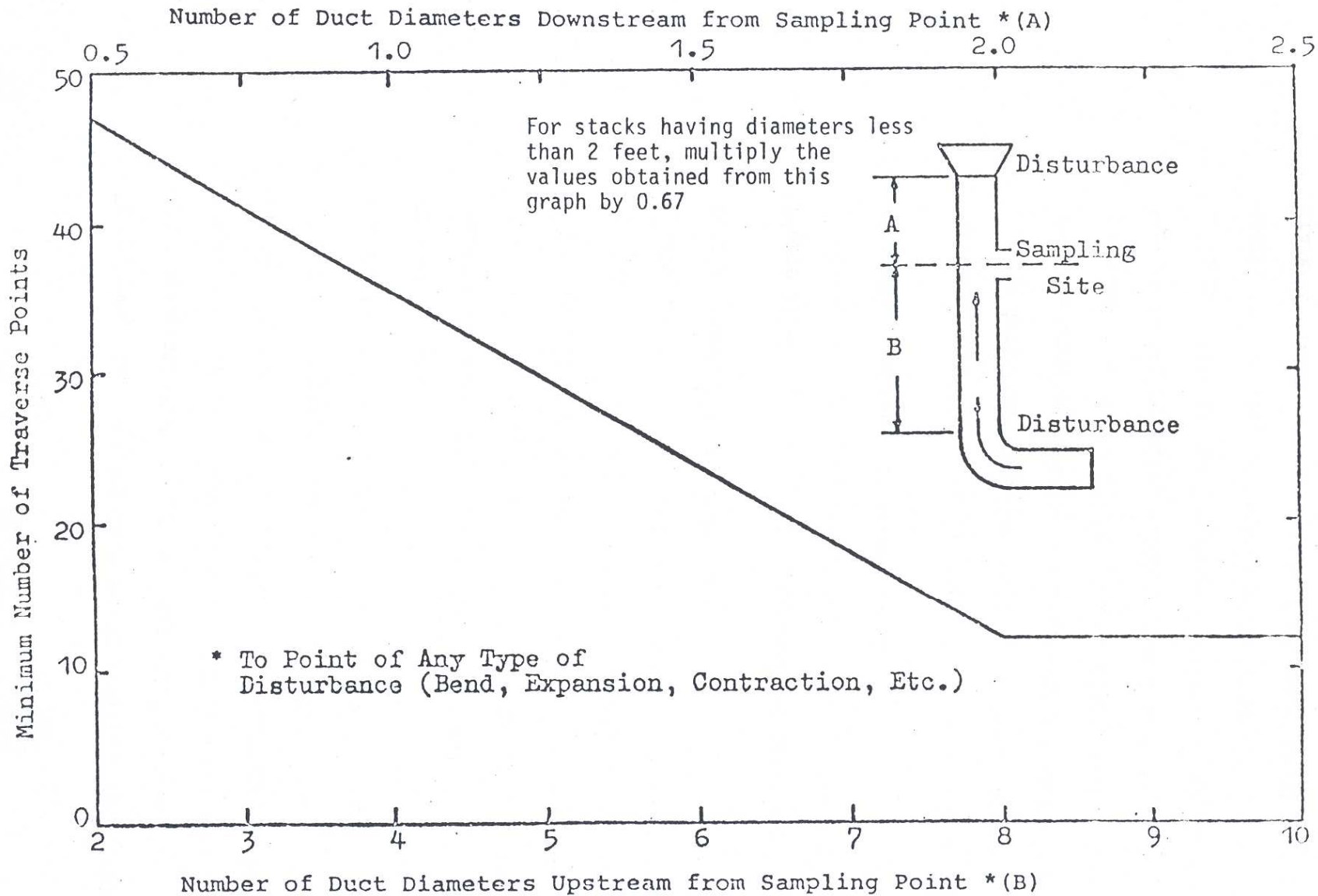
Minimum Number of Traverse Points

FIGURE III-2: MINIMUM NUMBER OF TRAVERSE POINTS

Where field measurements show that there is less than those distances from the sampling point to disturbances, the minimum number of traverse points is determined from Figure III-2. For stacks having diameters less than 2 feet, multiply the values from Figure III-2 by 0.67.

If the cross section of the stack is other than circular, the equivalent diameter for use with Figure III-2 can be calculated from

$$D \text{ equiv.} = 4\left(\frac{\text{area}}{\text{perimeter}}\right) = 2\left(\frac{L \times W}{L + W}\right)$$

$$= 2\left(\frac{L \times W}{L + W}\right) \qquad (3\text{-}19)$$

where
L	=	Length
W	=	Width

To determine the location of traverse points, first divide the stack cross-section into as many equal areas as the required number of traverse points. Locate a traverse point at the centroid of each area. This is illustrated in Figure III-3 for a circular stack and in Figure III-4 for a rectangular stack. Figure III-3 shows two alternative methods for setting 12 traverse points. The first method requires one sampling port and the other requires two. Even with two ports, it may be desirable to use the first method and make two traverses on the two diameters shown. If particulate sampling is to be done later, the first sample run can be made according to one traverse and the second according to the other traverse.

Figure III-4 indicates that three sampling ports may be necessary for a rectangular stack, depending upon the stack dimensions and the size of the ports.

The location of traverse points in circular stacks can be readily determined from Table III-1. Under no condition should a traverse point be selected within 1 inch of the stack wall. When any of the traverse points fall within 1 inch of the stack walls, relocate them away from the stack walls to a distance of 1 inch or a distance equal to the nozzle inside diameter, whichever is larger. These relocated traverse points (on each end of a diameter) shall be "adjusted" traverse points. Whenever two successive traverse points are combined to form a single adjusted traverse point, treat the adjusted point as two separate traverse points.
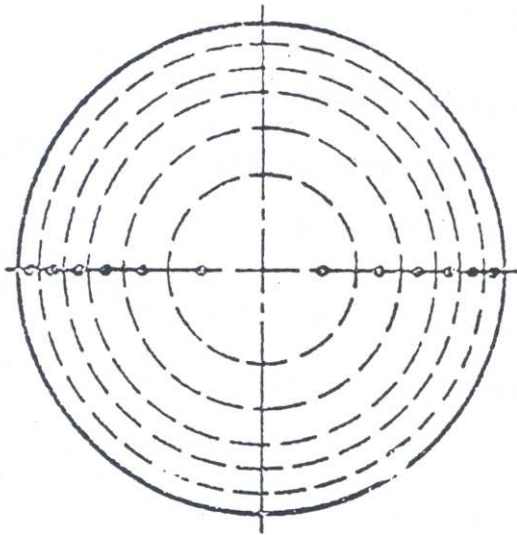
12 Equal Areas Half Annuli   12 Equal Areas Quarter Annuli
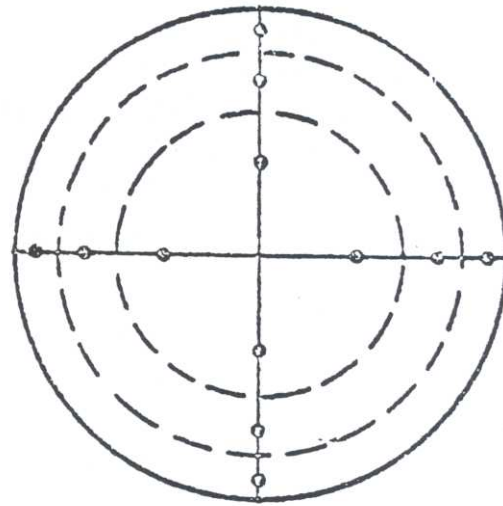
FIGURE III-3

CROSS SECTION OF CIRCULAR STACK
DIVIDED INTO 12 EQUAL AREAS WITH A TRAVERSE
POINT AT THE CENTROID OF EACH AREA

FIGURE III-4

CROSS SECTION OF RECTANGULAR STACK
DIVIDED INTO 12 EQUAL (RECTANGULAR) AREAS,
WITH A TRAVERSE POINT AT THE CENTROID
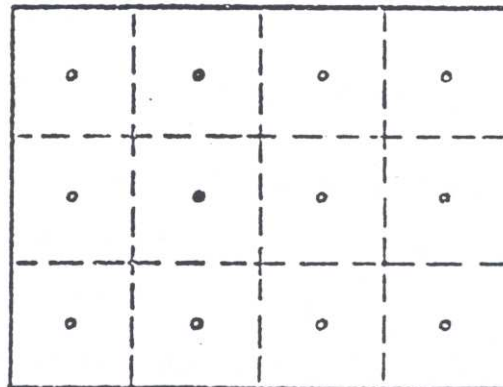OF EACH AREA

TABLE III-1: LOCATION OF TRAVERSE POINTS IN CIRCULAR STACKS

(Percent of stack diameter from inside wall to traverse point)

Traverse point number on a diameter	Number of traverse points on a diameter											
	2	4	6	8	10	12	14	16	18	20	22	24
1	14.6	6.7	4.4	3.3	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	85.4	25.0	14.7	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3		75.0	29.5	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4		93.3	70.5	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5			85.3	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6			95.6	80.6	65.8	35.5	26.9	22.9	18.8	16.5	14.6	13.2
7				89.5	77.5	64.5	36.6	28.3	23.6	20.4	18.0	16.1
8				96.7	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9					91.8	82.3	73.1	62.5	38.2	30.6	26.1	23.0
10					97.5	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11						93.3	85.4	78.0	70.4	61.2	39.3	32.3
12						97.9	90.1	83.1	76.4	69.4	60.7	39.8
13							94.3	87.5	81.2	75.0	68.5	60.2
14							98.2	91.5	85.4	79.6	73.9	67.7
15								95.1	89.1	83.5	78.2	72.8
16								98.4	92.5	87.1	82.0	77.0
17									95.6	90.3	85.4	80.6
18									98.6	93.3	88.4	83.9
19										96.1	91.3	86.8
20										98.7	94.0	89.5
21											96.5	92.1
22											98.9	94.5
23												96.8
24												98.9

For circular stacks, determine the distance from the inside stack wall to each traverse point from Table III-1. Add to each such distance the dimension from the inside stack wall to a fixed reference point, such as the outside edge of the sampling port. Mark the pitot with a line representing this distance and a traverse point number for each traverse point as positioning guides.

For rectangular stacks, the pitot may have to be inserted at an angle to reach some of the traverse points. Sketch the stack cross-section showing the location of each traverse point and determine the positioning guide mark and the angle for each traverse point.

3.1.3 Velocity Traverse (Method 2)

Principle. The average gas velocity in a stack is determined from the gas density and from measurement of the average velocity head with a Type S pitot tube.

Applicability. This method is applicable for measurement of the average velocity of a gas stream and for quantifying gas flow.

This procedure is not applicable to measurement sites which fail to meet the criteria of Method 1, Section 3.1.2. Also, the method cannot be used for direct measurement in cyclonic or swirling gas streams. When unacceptable conditions exist, alternative procedures, subject to the approval of the Executive Officer, Air Resources Board, must be employed to make accurate flow rate determinations; examples of such alternative procedures are:

(i)   to install straightening vanes;
(ii)   to calculate the total volumetric flow rate stoichiometrically, or
(iii)   to move to another measurement site at which the flow is acceptable.

Verify the existence or absence of cyclonic flow. Before conducting the velocity traverse level and zero the manometer. Connect a Type S pitot tube to the manometer and position the pitot tube at each traverse point, in succession, so that the planes of the face openings of the pitot tube are perpendicular to the stack cross-sectional plane: when the Type S pitot tube is in this position, it is at "0° reference." If null (zero) pitot readings a re obtained at 0° reference, acceptable flow conditions exist. If the pitot readings are not zero at 0° reference, unacceptable flow conditi ons exist and some type of flow straightening must be used to induce suitable flow conditions for isokinetic sampling.

Having verified the absence of cyclonic flow, conduct the velocity traverse. Traverse the stack with the pitot and record the manometer reading at each traverse point on a field data sheet, such as Appendix III-2, under the column "Velocity Head." Record also the temperature reading from the potentiometer for each traverse point. If a negative manometer reading is obtained at a traverse point, move the pitot slightly forward or backward and the negative reading should disappear. If it does not, record the reading as zero. Be careful to align the pitot along the axis of the stack during the traverse. Do not orient the pitot for the maximum manometer readings, which can occur when the pitot is aligned as much as 30 degrees from the axis of stack. Using such readings can introduce a significant error.

On the data sheet, calculate the average velocity head for the traverse by summing the individual velocity heads and dividing by the number of traverse points, according to the equation

$$\frac{\sum(\Delta Pn)}{n} = (\Delta P)\,\text{avg.} \qquad\qquad (3\text{-}20)$$

This average velocity head will be used later in selecting the proper size sampling nozzle for particulate matter sampling.

On the data sheet, calculate the square root of the velocity head ($\sqrt{\Delta P}$) for each traverse point. Sum these values and divide by the number of traverse points, according to the equation

$$\frac{\sum\sqrt{(\Delta P)}\,n}{n} = \left(\sqrt{\Delta P}\right)\text{avg.} \qquad\qquad (3\text{-}21)$$

($\sqrt{\Delta P}$) avg. is the value used to calculate the average stack gas velocity, U_s, in equation (3-9). A calculation sheet showing this equation is given as Appendix III-1.

On the data sheet, calculate the average stack gas temperature in $^\circ$F by summing the individual temperatures and divid ing by the number of traverse points, according to the equation

$$\frac{\sum Tn}{n} = T\,\text{avg.} \qquad\qquad (3\text{-}22)$$

Convert this average to absolute temperature by adding 460, according to the equation

$$T \text{ avg.} + 460 = T_s \text{ avg.} \qquad (3\text{-}23)$$

T_s avg is the absolute stack gas temperature in °R that is used in equations (3-9) and (3-18) to calculate average stack gas velocity and flow rate, respectively. These two equations are given on the calculation sheet, Appendix III-1.

Record the atmospheric pressure reading from the aneroid barometer on the line on the data sheet, Appendix III-2, Barometric Pressure. If an aneroid barometer is not available, obtain the barometric pressure from a nearby airport or weather bureau. Make sure the data thus obtained has not been corrected to sea level.

The static pressure of the stack is also measured. This may be accomplished concurrently with the velocity traverse by rotating the pitot tube 90° from the alignment used in the velocity traverse so that the pitot tube openings are perpendicular to the stack cross-sectional plane. Disconnect one of the pitot tube tubings from the manometer and measure the static pressure at several traverse points. Convert the manometer reading (inches H_2O) to inches mercury by dividing by 13.6, which is the specific gravity of mercury with respect to water, and then average these values for the static pressure of the stack.

Add the static stack pressure to the barometric pressure and record on the data sheet Appendix III-2 as Stack Pressure.

In many practical cases, the sampling port in the stack is relatively close to the stack outlet and the stack pressure may not differ significantly from the atmospheric pressure. In these cases, record the barometric pressure also as the Stack Pressure.

3.2   Molecular Weight (Ms)

Generally for combustion sources, the stack gas should be analyzed for water vapor (H_2O), carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2). The remainder of the gas is assumed to be nitrogen (N_2). For many non-combustion sources, it may be safe to assume that the gas is dry air plus water vapor.

Methods for determining the water vapor content are discussed in Chapter V. The method for determining the other constituents listed above by Orsat analysis is discussed in Chapter IV.

The apparent molecular weight of the stack gas is calculated from the following equation.

$$M_s = B_{wo} M_{H2O} + (1-B_{wo})(B_{CO2} M_{CO2} + B_{O2} M_{O2} + B_{CO} M_{CO} + B_{N2} M_{N2})$$

$$(3\text{-}24)$$

where
M_s	=	Molecular weight of the stack gas
M_x	=	Molecular weight of a component
B_x	=	Volume fraction of a component as measured by the Orsat analyzer.
B_{wo}	=	Volume fraction of water vapor

This equation is tabulated for ease in doing the calculations on the calculation sheet, Appendix III-1. The value for M_s so derived is used in determining average stack gas velocity, U_s, in equation (3-9). This equation for U_s is also given on Appendix III-1.

APPENDIX III

TABLE OF CONTENTS

State of California   File No. _____

AIR RESOURCES BOARD

Stationary Source Control Division
Engineering Evaluation Branch

VELOCITY AND FLOW RATE CALCULATIONS

A.   <u>Stack Gas Molecular Weight</u> (M_s)

Component	Volume % / 100	Factor $(1-B_{wo})$	Molecular Weight of Component	$\dfrac{Vol\%}{100}$ x Factor x M_{sn}
H_2O (Vol. %)		1.0	18	
CO_2			44	
O_2			32	
CO			28	
N_2			28	
			$M_s =$	

B.   <u>Stack Area</u> (A_s)

A_s = _____

A_s = _____ft^2

C.   <u>Stack Velocity</u> (V_s)

$$V_s = 85.42\, C_p \left(\sqrt{\Delta P}\right)_{avg} \sqrt{\dfrac{T_s}{P_s M_s}}$$

$$V_s = 85.42\, (\quad\quad)(\quad\quad) \sqrt{\dfrac{(\quad\quad\quad)}{(\quad\quad)(\quad\quad)}} = \text{_____ fps}$$

D.   <u>Standard Flow Rate (Dry Basis)</u> (Q_s)

$$Q_s = 60\, \dfrac{T_{std}}{P_{std}} \left(1 - B_{wo}\right) V_s A_s \dfrac{P_s}{T_s}$$

$$Q_s = (60)(17.65)(\quad\quad)(\quad\quad)(\quad\quad) \dfrac{(\quad\quad\quad)}{(\quad\quad\quad)} = \text{_____ SDCFM}$$

State of California

AIR RESOURCES BOARD

Stationary Source Control Division
Engineering Evaluation Branch

VELOCITY TRAVERSE DATA

Traverse Point Number	Velocity Head in. H$_2$O	$\sqrt{\Delta P}$	Stack Temperature (T$_s$), °F	Velocity Head in. H$_2$O	$\sqrt{\Delta P}$	Stack Temperature (T$_s$), °F
Average						

Plant _____

Sampling Site _____
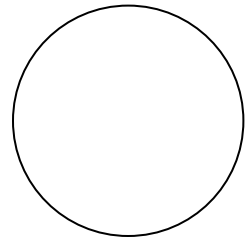
Remarks _____

_____

Barometric Pressure, in. Hg _____

Static Pressure in Stack (P$_g$) in. Hg _____

Operators _____ Date _____

MEASUREMENT OF VELOCITY OR VELOCITY HEAD[*]

No.	Measurement Means	Application	Range, fpm	Pre-cision	Limitations
1.	Hot-wire anemometer	(a) Low air velocities; directional and non-directional available	5-1,000	1-20%	Accuracy of some types not good at lower end of range.
		(b) High air velocities	up to 60,000	1-10%	
2.	Kata themo-meter	Low air velocities in rooms; nondirectional	5-300	5-15%	Awkward to use; affected by radiation.
3.	Smoke puff or airborne solid	Low air velocities in rooms; highly directional	5-50	10-20%	Awkward to use but valuable in tracing air movement.
4.	Deflecting-vane type anemometer	Air velocities in rooms, at outlets, etc.; directional	30-24,000	5%	Not well suited for duct readings; needs periodic check calibration.
5.	Venturi-type multiplying Pitot tube	Low air velocities in rooms and ducts; directional	100-2,000 with micromanometer; 180-2,000 with draft gages.	1-5%	Accuracy falls off at low end of range
6.	Revolving-vane type anemometer	Moderate air velocities in ducts and rooms; somewhat directional	100-2,000	5-20%	Extremely subject to error with variations in velocities with space or time; easily damaged; needs periodic calibration.
7.	Pitot tube	Std instrument for measurement of duct velocities and pressures	180-10,000 with micromanometer; 600-10,000 with draft gages; 10,000 up with manometer	1-5%	Accuracy falls off at low end of range
8.	Impact tube and sidewall or other static tap	High velocities, small tubes and where air direction may be variable.	120-10,000 with micromanometer; 600-10,000 with draft gages; 10,000 up with manometer.	1-5%	Accuracy depends upon constancy of static pressure across stream section.

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[*] ASHRAE Handbook of Fundamentals – American Society of Heating, Refrigerating and Air Conditioning Engineers Inc., New York, 1968.

MEASUREMENT OF DIFFERENTIAL PRESSURE[*]

No. Measurement Means	Application	Range	Precision	Limitations
1. Micromanometer	Very low press. diff.	0-6 in. H_2O	0.0005 in. H_2O	Not readily portable not easy to use with pulsating pressure.
2. Draft gages	Moderately low press. diff.	0-10 in. H_2O	0.005 in. – 0.05 in. H_2O	Must be leveled carefully
3. Manometer	Medium press. diff.	0-100 in. H_2O or Hg	0.05 in.	Where used with liquid must be compensated for liquid density.
4. Swinging-vane type gage	Moderately low press. diff.	0-1/2 in. H_2O 0-20 in. H_2O	5%	Generally usable to atmospheric pressure only.
5. Bourdon-tube type	Medium to high press. diff., usually to atmosphere.	Any	As high as 0.01 psi or 0.01% of full scale.	Subject to damage due to over press-shock or pulsation.
6. Pressure Transducers-strain gage, capacity, potentiometer, crystal, magnet.	Remote reading, responds to rapid changes to pressure	0.05 to 50,000 psi	0.1%	

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[*]   ASHRAE Handbook o Fundamentals – American Society of Heating, Refrigerating and Air Conditioning Engineers Inc., New York, 1968.

APPENDIX III-5

PITOT TUBE CALIBRATION

Calibration is best done in the laboratory. Measure the velocity head at a point in a flowing gas stream with both the pitot tube being calibrated and a standard pitot tube with a known coefficient. Vary the velocity of the flowing gas stream over the normal working range. In calibrating an "S" type pitot tube, compare the pitot coefficients determined first with one leg and then the other leg acting as the downstream leg. For a useable pitot tube, the coefficients should differ by no more than 0.01.

Calculate the pitot tube coefficient from the following equation

$$\text{CpTest} = \text{Cp std} \sqrt{\frac{\Delta P_{std}}{\Delta P_{test}}}$$

where

where

CpTest	=	Pitot tube coefficient of pitot being calibrated
Cp_{std}	=	Known pitot tube coefficient of standard pitot tube
ΔP_{std}	=	Velocity head measured by the standard pitot tube
ΔP_{test}	=	Velocity head measured by the pitot tube being calibrated

CHAPTER IV

CARRIER GAS ANALYSIS FOR MOLECULAR WEIGHT (METHOD 3)

1.   INTRODUCTION

This chapter discusses sampling and analyzing the stack gas to determine the volume percents of carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), and nitrogen (N_2). These values are used in calculating the molecular weight of the gas. The molecular weight is required in determining the average stack gas velocity, as discussed in Chapter III. The calculation of the molecular weight from the composition of the gas is discussed in Chapter III, Section 3.2. Analysis for the above listed gases, together with the moisture analysis discussed in Chapter V, are generally sufficient for determining the molecular weight of stack gas from a combustion source.

The standard Orsat Analyzer can be used for analyzing the stack gas either in the field or in the laboratory. There are other Orsat-type analyzers such as the "Fyrite" units. The analysis by either standard Orsat or "Fyrite" is accurate within 0.5%.

2.   STANDARD ORSAT ANALYSIS

    2.1   Equipment

        For field analysis only:

        •   Standard Orsat Analyzer, portable (see Figure IV-1)
        •   Stainless steel or pyrex glass probe equipped with a glass wool filter
        •   Non-reactive, thermally stable flexible tubing, to make connections.

        For field or laboratory analysis:

        •   Use the same equipment as above, except that the analyzer need not be portable and more flexible tubing may be needed.
        •   Add the following:
            -    Plastic bag, ¼ to ½ ft^3 capacity, aluminized mylar, tedlar, or equivalent
            -    Vacuum pump or squeeze bulb, to transfer sample to plastic bag.

    2.2   Procedure

        If the plastic bag is not used, connect probe to analyzer and proceed to the numbered steps below.
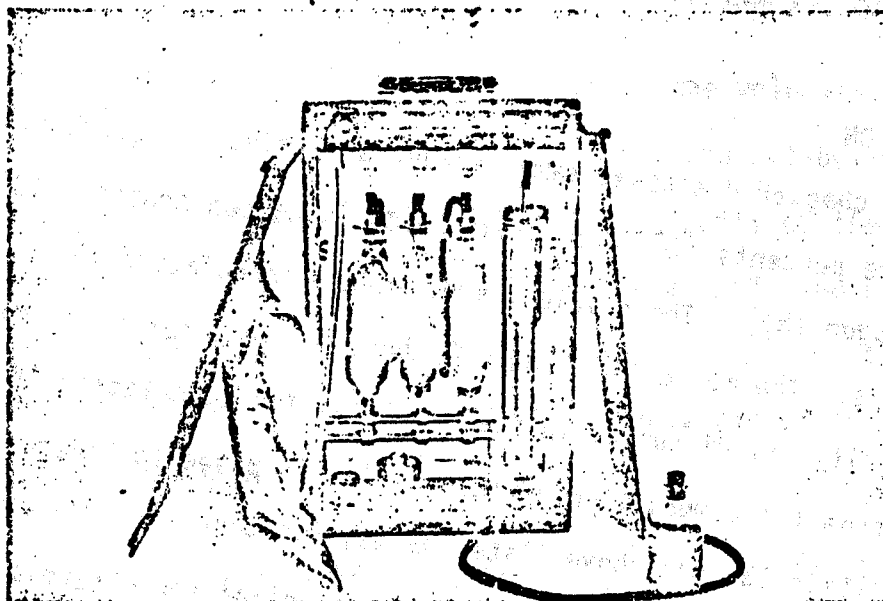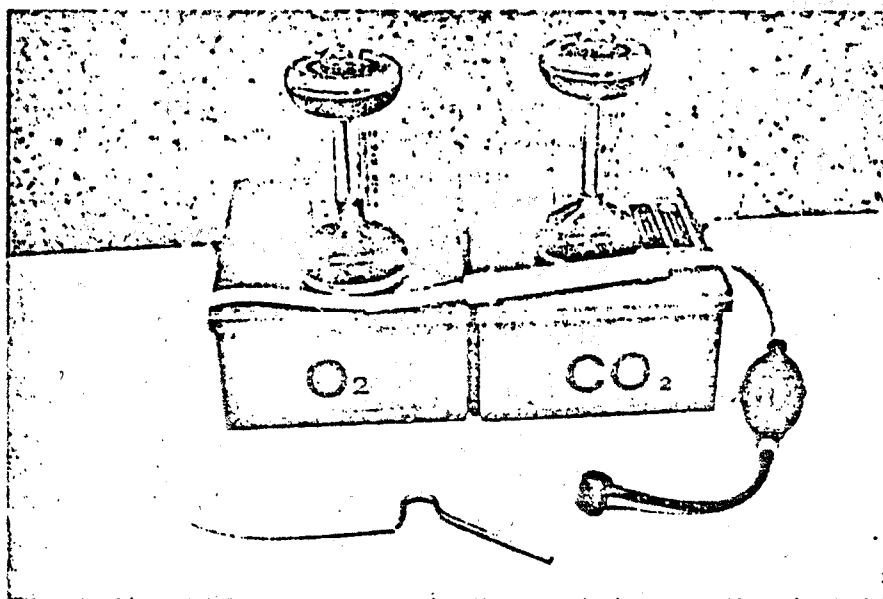
FIGURE IV-1: ORSAT ANALYSER

FIGURE IV-2: "FYRITE" ANALYSER

If the plastic bag is used, set up the equipment as shown in Figure IV-1 (Chapter VI) and check for leaks. Connect the pump, or the squeeze bulb, and draw stack gas into the plastic bag. In some cases, it may be desirable to draw an integrated sample. This is done by filling the bag in increments spread equally over several minutes.

Each equipment manufacturer supplies instruction which should be followed in using his equipment. In general, the procedure is as follows:

1. Be sure that burettes are filled with the proper solutions and brought to the proper fluid levels. Purge all lines with stack gas. Shut all valves.

2. Open the sample valve and draw gas into the analyzer by lowering the leveling bottle.

3. Shut the intake and expel the sample by opening the atmospheric valve and raising the leveling bottle.

4. Repeat steps 2 and 3 several times so that the analyzer is flushed out and the water in the leveling bottle becomes saturated with the gas to be sampled.

5. Fill graduated burette with sample by opening the sample valve and lowering the leveling bottle

6. Shut sample valve and flush gas sample through the CO_2 absorber several times by slowly raising and lowering the leveling bottle.

7. Draw the gas sample back into the graduated burette, shut off the CO_2 absorber valve, and read the volume decrease. When taking the reading it is important that the water levels in the burette and leveling bottle are the same. Repeat steps 6 and 7 until a stable reading is achieved. Record the volume decrease as % CO_2 on the data sheet in Appendix III-1, Chapter III.

8. Repeat steps 6 and 7 for the O_2 and CO absorbers in that order. Record the volume decreases as % O_2 and % CO, respectively on the data sheet in Appendix III-1, Chapter III.

9. Expel the remainder of the sample and the apparatus is ready to analyze another sample.

2.3   Cautions

1.   Equipment leaks will cause ambient air to be drawn in, diluting the sample, and resulting in erroneous readings.

2.   Always pass the gas sample in sequence through the CO_2, O_2, and CO absorbing solutions. The O_2 solution will also absorb CO_2, and the CO solution will also absorb O_2.

3.   If more than 10 passes are required through one of the absorbers before a stable reading is achieved, the solution should be replaced.

3.   "FYRITE" UNIT ANALYSIS

The "Fyrite" units are Orsat-type analyzers which are less expensive and much simpler to operate than the standard Orsat Analyzer (see Figure IV-2). The stack gas is hand-aspirated into plastic absorption flasks which are manually agitated and easily measured for composition of CO_2 or O_2. There is no "Fyrite" unit for CO. However, there is no error introduced by counting the CO as N_2 since the molecular weights are the same.

CHAPTER V

DETERMINATION OF MOISTURE CONTENT (METHOD 4)

1.   INTRODUCTION

This chapter discusses the condensation method and the wet-and-dry bulb temperature method of determining the volume fraction of water vapor in the stack gas.

This moisture content is required to determine the velocity and flow rate (dry basis) of the stack gas, as discussed in Chapter III. It is also needed in particulate matter source tests for determining the pollutant concentration and the required sampling rate.

The moisture content of a gas is determined by either a condensation and absorption or a psychrometric method. For source testing purposes the condensation method is generally used. It is effective for all moisture contents greater than 1 %. The wet and dry bulb temperature method is easier to use, but its application is limited.

2.   CONDENSATION METHOD

The condensation method involves impingers in an ice bath, which condense the moisture from the gas stream. The condensed water is measured volumetrically and compared with the total volume of the gas measured by a gas meter.

All of the moisture is not collected in the condenser, since the gas leaving the condenser is saturated with water vapor. If this water vapor is collected with an absorbing agent such as silica gel, only dry gas is measured by the meter. The total volume of water vapor in the stack gas is therefore equal to the volume of water vapor collected by the condenser, plus the volume of water vapor collected by the silica gel. The volume of dry gas is read from the gas meter.

Before these volumes can be compared they must be calculated at the standard conditions of 68°F and 29.92 in Hg. The method of calculation is summarized in Appendix IV-1.

2.1   Volume of Dry Gas

        If we assume that the volume of dry gas at the condenser is equal to the volume of gas at the meter, the volume of dry gas at standard conditions becomes

$$Vm_{std} = Vm \bullet \frac{Pma \bullet Tstd}{Tm \bullet Pstd} \qquad (5\text{-}1)$$

where

Vm_{std} =   Volume of dry gas at standard conditions
Vm =   Volume of dry gas at condenser (read at meter)
Pma =   Absolute pressure at meter
Tm =   Absolute temperature at meter

Using EPA type equipment the meter pressure can be obtained by reading the pressure drop across the orifice at the meter, dividing the value by 13.6, and adding the quotient to the barometric pressure.

2.2   Volume of Wet Gas

The volume of water vapor that passes through the condenser could be measured by weighing the silica gel before and after the test. However, the volume can be calculated from a Saturation Vapor Pressure Over Water Curve shown in Appendix V-2 and the condenser (or impinger) temperature. The volume of the water vapor can be obtained from the partial pressures of water vapor and dry gas or from the equation

$$V_{wv\,std} = \frac{V_{m\,std}\ (V.P.)}{Pma\ \text{-}\ (V.P.)} \qquad (5\text{-}2)$$

where

$V_{wv\,std}$ =   Volume of water vapor at standard conditions
$V_{m\,std}$ =   Volume of dry gas at standard conditions
$(V.P.)$ =   Vapor pressure of water at condenser exit temperature
Pma =   Absolute pressure at the meter.

Applying the ideal gas law to the volume or mass of water vapor condensed, i.e. – (the mass of 1 ml H_2O = 1 gm).

$$P_{std}\,V_{wc} = \frac{R\ V_{LC}\ T_{std}}{M_{H_2O}} \qquad (5\text{-}3)$$

where

P_{std} =   Standard pressure of in Hg.
V_{wc} =   Volume of water vapor collected, ft^3
R =   Universal gas constant,

$$0.0481\ \frac{in\,Hg\,ft^3}{GM\ MOLE\ {}^{\circ}R}$$

$$V_{LC} = \text{Volume of water collected at condenser, ml.}$$
$$M_{H_2O} = \text{Molecular weight of water} = 18$$
$$T_{std} = \text{Standard temperature, } °R.$$

This equation reduces to

$$V_{wc_{std}} = 0.00267 \ V_{LC} \ \frac{T_{std}}{P_{std}} \qquad\qquad (5\text{-}4)$$

The volume of wet gas at standard conditions is then equal to

$$V_{w_{std}} = V_{wv_{std}} + V_{wc_{std}} \qquad\qquad (5\text{-}5)$$

and the volume fraction of water vapor in the gas stream is equal to

$$B_{wo} = \frac{V_{wv_{std}} + V_{wc_{std}}}{V_{m_{std}} + V_{wv_{std}} + V_{wc_{std}}} \qquad\qquad (5\text{-}6)$$

2.3 Oversaturated Conditions

If the gas stream is oversaturated, excessive water will collect in the condenser and result in a larger water vapor content than could exist in the stack gas. This often happens when sampling sources with wet scrubbers.

If the calculated volume of the wet gas exceeds the saturated volume of the gas (at stack temperature) or if the calculated moisture content exceeds the saturated water content, the saturated water content must be used. A psychrometric chart which gives the percent water vapor at saturation is shown in Appendix V-3.

2.4 Field Operations

2.4.1 Equipment

1. Probe – stainless steel or pyrex glass

2. Condensers – 4-500 ml modified Greenberg Smith Impingers

3. Ice Bath Container

4. Silica Gel and Tube

5. Needle Valve – to regulate gas flow

6.   Pump – leak free, diaphragm type

7.   Dry Gas Meter

8.   Graduated Cylinder – 250 ml

9.   Barometer – (accurate to 0.1 in Hg.)

10.   Thermometer – (for meter)

11.   Thermometer or Thermocouple – (for last impinger)

12.   Tubing and Fittings – (to connect components)

2.4.2 Procedure

Place exactly 100 ml. distilled water in the first two impingers. Assemble the apparatus without the probe as shown in Figure V-1. Leak-check by plugging the inlet to the first impinger and drawing a vacuum. Ensure that leakage through the dry gas meter is less than 1% of the sampling rate.

Connect the probe and sample at a constant rate of 0.75 – 1.00 CFM. Continue sampling until the dry gas meter registers a total volume of 15 cubic feet or until visible liquid droplets are carried over from the first impinger to the second. Record temperatures, pressure, and dry gas meter readings on the data sheet in Appendix V-1. After collecting the condensed water sample, measure its volume to the nearest 0.5 ml and record on the data sheet. Calculate moisture content in the stack gas (B_{wo}) on the data sheet.

3.   WET AND DRY BULB TEMPERATURE METHOD

The moisture content of the stack gas may also be determined from the wet- and dry-bulb temperatures, using a Psychrometric chart and a Saturation Vapor Pressure Over Water Curve.

FIGURE V-1 MOISTURE SAMPLING TRAIN
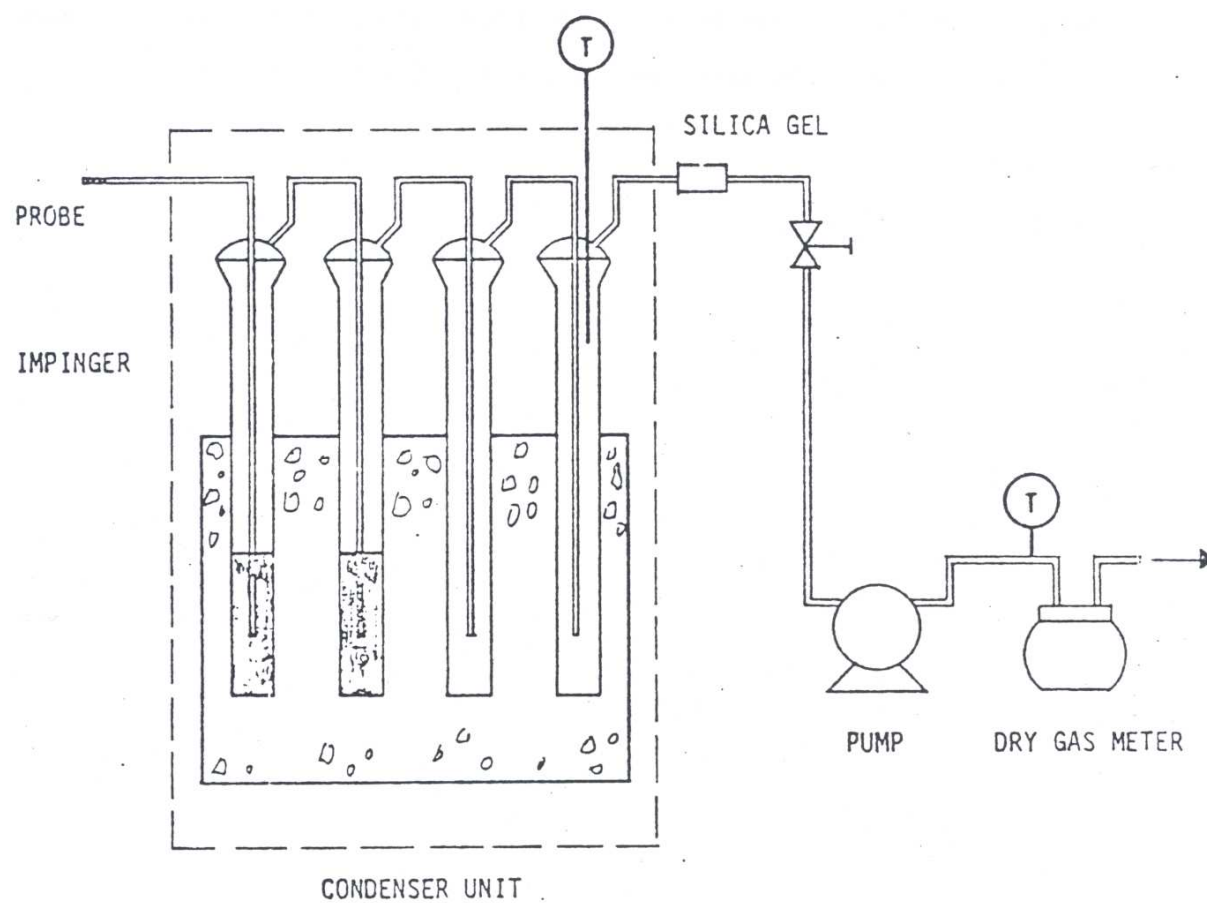
LEGEND:

    MODIFIED GREENBERG-SMITH IMPINGER CONTENT:
        NO. 1 AND 2 – 100 ML. DEIONIZED DISTILLED WATER
        NO. 3 AND 4 – DRY

The relative humidity is determined from the psychrometric chart (Appendix V-4) from the intersection of the wet and dry bulb temperatures. The saturated vapor pressure is then obtained from the Saturation Vapor Pressure Over Water Curve (Appendix V-2) at the dry bulb temperature.

The wet bulb and dry bulb temperature method can be used for approximating the pre-run moisture content of the stack gas. It is much faster and simpler than the condensation method, but is limited to cases where the moisture content is less than 15 percent, and dewpoint temperature is less than 126°F, and the velocity pa st the wet-bulb is between 10 and 30 ft/sec.

RANGE = 200°F

DRY BULB
THERMOMETER

WET BULB
THERMOMETER

WICK
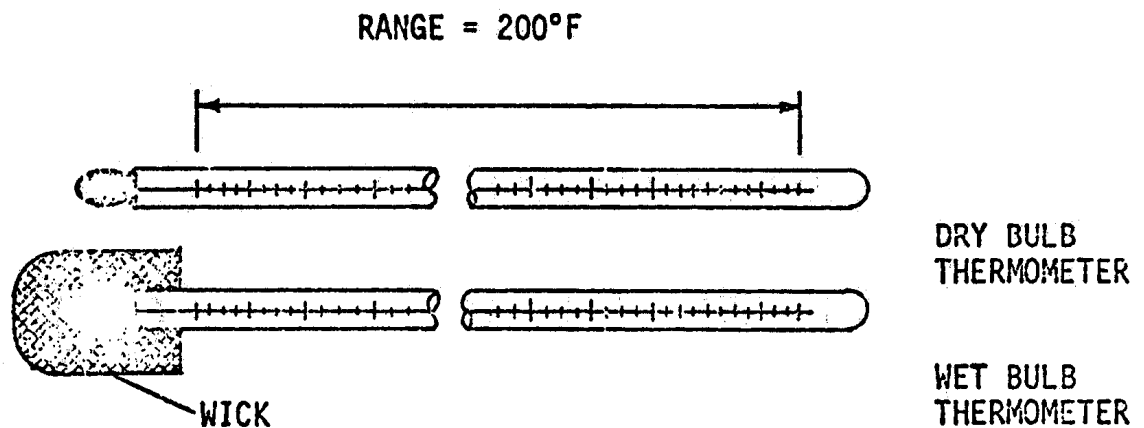
FIGURE V-2: WET AND DRY BULB THERMOMETERS

Read the relative humidity (R.H.) from the psychrometric chart in Appendix V-4, and the vapor pressure (V.P.) from the curve in Appendix V-2. Calculate the volume fraction of water vapor in the stack gas (B_{wo}) from the equation below. Record the calculated B_{wo} on the data sheet in Appendix V-1.

$$B_{wo} = \frac{(R.H./100)(V.P.)}{P_s} \qquad (5\text{-}7)$$

where
  R.H. = Relative Humidity
  V.P. = Saturated vapor pressure
  P_s = Absolute stack pressure proportion of volume

Alternatively, read the volume percent water vapor from the psychrometric chart in Appendix V-3, divide by 100 to obtain volume fraction of water vapor (B_{wo}), and record on the data sheet in Appendix V-1.

APPENDIX V

1.   WATER VAPOR CALCULATIONS AND DATA SHEET

2.   SATURATION VAPOR PRESSURE OVER WATER CURVE

3.   PSYCHROMETRIC CHART FOR AIR-WATER VAPOR MIXTURES

4.   HIGH TEMPERATURE PSYCHROMETRIC CHART

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AIR RESOURCES BOARD

<u>WATER VAPOR CALCULATIONS</u>
Standard Conditions 68°F and 29.92 in. Hg

Ambient Conditions ____°F and _____ in. Hg

Time	Gas Volume Through Meter (V_m), Ft^3	Impinger Temp. (T_i), °F	Meter Temp. (T_m), °F	Orifice Pressure (Δh), in. H_2O	Volume of Water Collected in Impinger (V_{lc}), ml	
					Final	
					Initial	
					Net (V_{lc})	

A.   <u>Gas Volume Metered</u> (V_{mstd})

$$P_{ma} = P_{bar} + (\Delta H / 13.6) = (\quad) + \frac{(\underline{\quad})}{13.6} = \underline{\qquad} \text{in. Hg}$$

$$V_{m_{std}} = \frac{528°R}{29.92 \text{ in. Hg}} \cdot \frac{V_m P_{ma}}{T_m} = (17.65) \frac{(\underline{\quad})(\underline{\quad})}{(\underline{\quad})} = \underline{\qquad}\text{SDCF}$$

B.   <u>Volume of Water Collected</u> (V_{wstd})

$$V_{w_{std}} = \left(0.04707 \; {}^{Ft^3}\!/_{ml}\right)\left(V_{l_c}\right) = (0.04707)(\quad) = \underline{\qquad}\text{SCF}$$

C.   <u>Volume of Water Vapor at Impinger Temp</u> (V_{wvstd})

V.P. = _____ in. Hg at T_i = _____ °F

$$V_{wv_{std}} = \frac{\left(V_{m_{std}}\right)(V.P.)}{\left(P_{ma} - V.P.\right)} = \frac{(\underline{\quad})(\underline{\quad})}{(\underline{\quad})} = \underline{\qquad} \text{ SCF}$$
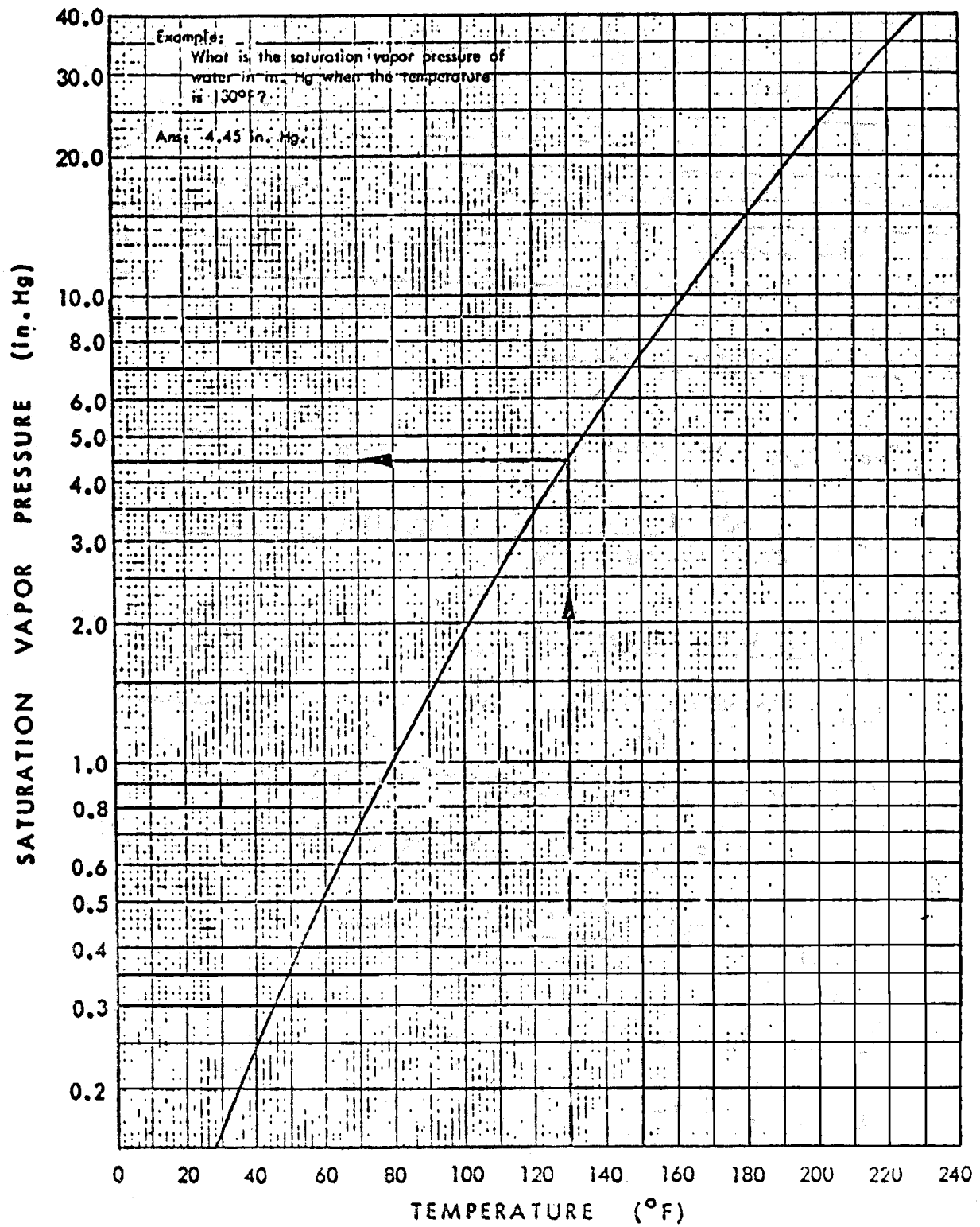
D.   Moisture Content in Stack Gas (B_{wo})

$$B_{wo} = \frac{B + C}{A + B + C} = \frac{(\qquad)}{(\qquad)} = \underline{\qquad}$$
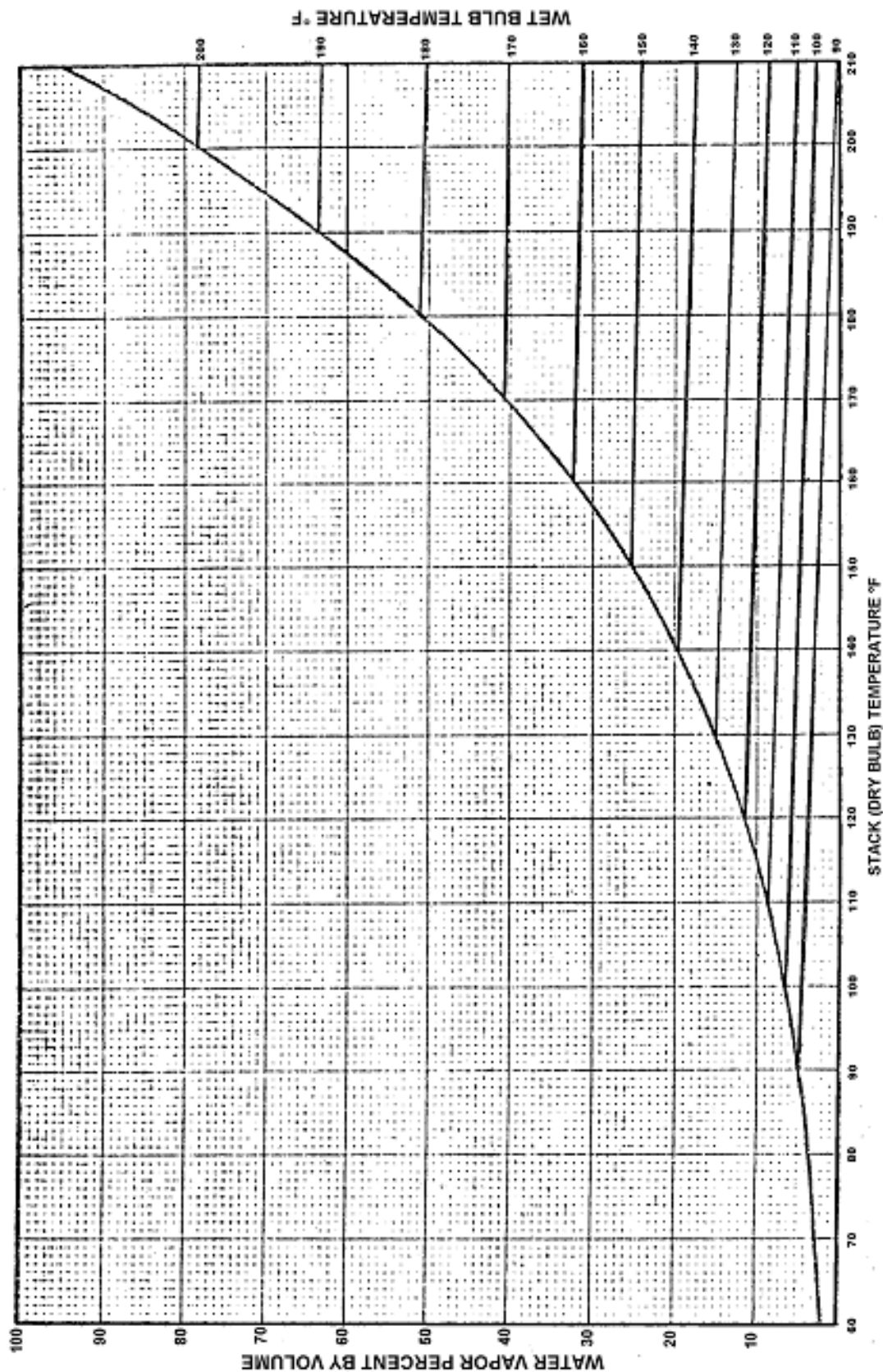
E.   Moisture Content at Saturation at Ts of _____°F

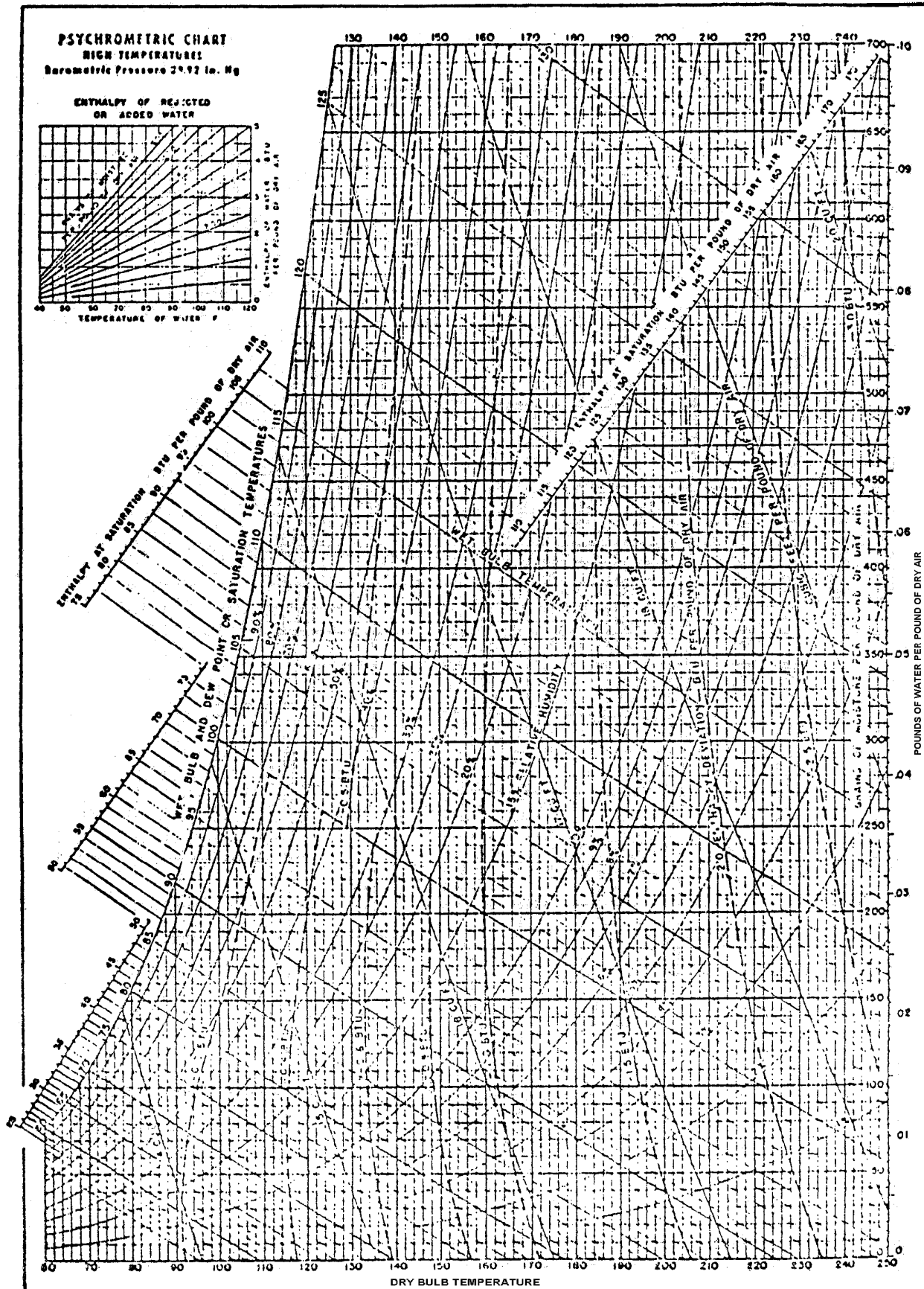B_{wo} = _____.   Use E if D > E.

APPENDIX V-2

SATURATION VAPOR PRESSURE OVER WATER CURVE

APPENDIX V-3

PSYCHOMETRIC CHART FOR AIR-WATER VAPOR MIXTURES

(AT 29.92 IN. HG.)

HIGH TEMPERATURE PSYCHROMETRIC CHART

CHAPTER VI

METHODS BASED ON GRAB SAMPLING
HYDROCARBONS, NO$_X$, CO

1.   INTRODUCTION

This chapter discusses the source test methods for hydrocarbons and oxides of nitrogen (NO$_x$). The method for hydrocarbons was devised by the ARB staff and the State Department of Health. The method of NO$_x$ is similar to ARB Method 7. This chapter also briefly discusses the non-dispersive infrared procedure for carbon monoxide (CO) that is in the ARB Method 10.

2.   GRAB SAMPLING AND INTEGRATED SAMPLING

In general, grab sampling provides a sample of gas that can be analyzed later. The method for NO$_x$ is an exception in that the grab sample of gas is immediately reacted with a chemical solution. Grab sampling might be used for a number of gases that are not covered in this manual. Care must be taken that the sample container is inert to the gas being sampled and that the sample will not otherwise degrade significantly by the time it is analyzed.

Ideally, a grab sample taken to determine compliance with APCD regulations should be taken instantaneously at the time that the stack emissions are at the maximum concentration. In practice, this is seldom possible.

An integrated sample can be taken by sampling into a container continuously over an extended time period. An integrated sample can be approached by sampling for a short time at intervals distributed over an extended period. In some cases, such sampling may be desirable. However, in most cases, a grab sample taken as rapidly as possible is adequate.

Remember always to take one or more duplicate samples.

3.   HYDROCARBONS

This method was devised by the ARB staff and the State Department of Health. A grab or integrated sample is taken and analyzed with a gas chromatograph.

    3.1   Equipment

        1.   Probe – stainless steel or pyrex glass, equipped with glass wool filter to remove particulate matter.

        2.   Flexible tubing – non-reactive and thermally stable.

3. Pump, leak-free, or Squeeze Bulb (to transfer sample to sample bag or sample bottle)

4. Sample bag – ¼ to ½ ft.^{3} capacity, plastic, aluminized Mylar or tedlar, equipped with a quick disconnect and a plug.

5. Gas sample bottle – glass, 250-300 ml. capacity, equipped with teflon stopcock at both ends.

6. Aneroid barometer

7. Thermometer (to measure ambient temperature)

8. Gas chromatograph – properly equipped for hydrocarbon analysis

3.2 Sampling Procedure

Trace amounts of benzene, toluene, xylenes and other compounds, if present, will plate out on the inside surface of a plastic bag. Therefore, use the plastic bag for total hydrocarbons exclusive of the above compounds, and use the gas sample bottle for the benzene, toluene, etc.

3.2.1 Gas Sample Bottle

Connect probe and gas sample bottle to pump (or squeeze bulb) with flexible tubing. The arrangement is as in Figure VI-1, except that the gas sample bottle replaces the plastic bag.

Insert probe through sampling port into gas stream and seal around probe at port. Open stopcocks on bottle. Start pump and purge lines and bottle with stack gas. Record barometric pressure, ambient temperature and other data on log sheet shown in Appendix VI-1. Close stopcock that is open to atmosphere. Stop pump. Close other stopcock.

Mark sample for identification and enter mark on log sheet. Remove bottle. Repeat for one or more duplicate samples.

3.2.2 Sample Bag

Connect probe to pump (or squeeze bulb). Connect tubing to pump with quick-disconnect fitting open to atmosphere. Insert probe through port and seal around probe at port. Start pump and purge lines. Record barometric pressure, ambient temperature and other data on log sheet. (Appendix VI-1). Remove plug from plastic bag
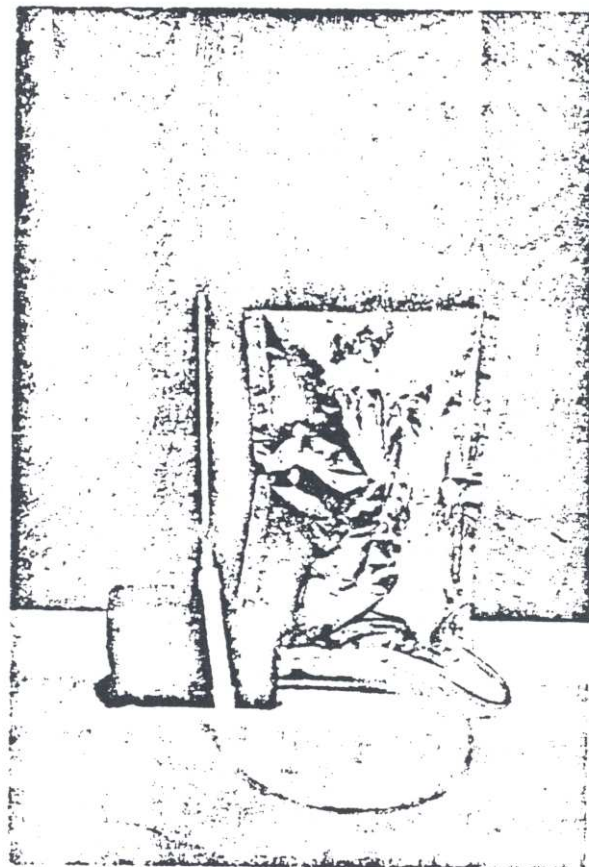
FIGURE VI-1: GRAB SAMPLING APPARATUS
(FLEXIBLE BAG METHOD)

and press air out of bag. Connect bag to quick-disconnect fitting and draw sample. Remove bag and insert plug. Stop pump. Mark sample for identification and enter mark on log sheet. Repeat for one or more duplicate samples.

3.3 Sample Analysis

The samples can be analyzed in the field or in the laboratory with a gas chromatograph. The sample analysis can be reported directly in parts per million (ppm) concentration of hydrocarbons in the sample. Calculations are not necessary unless the mass emission rate (lbs/hr) is wanted.

As desired, the results can be reported as total hydrocarbons in terms of methane equivalent, or as the concentration of each component listed separately, or both.

Record the test results in the blank lines on the sheet "Summary of Test Results" shown in Appendix X-2.

4. OXIDES OF NITROGEN (NO$_X$)

A grab sample is taken in an evacuated flask which contains a solution of dilute sulfuric acid and hydrogen peroxide. The NO$_x$, except for nitrous oxide (N$_2$O), is determined colorimetrically using the phenoldisulfonic acid (PDS) procedure.

4.1 Equipment

1. Probe – stainless steel or pyrex glass, heated if necessary to prevent condensation of water, with glass wool filter to remove particulate matter.

2. Collection flask – pyrex glass, 2-liter, round bottom with short neck and 24/40 standard taper opening, protected against implosion or breakage.

3. Flask valve – T-bore stopcock connected to a 24/40 standard taper joint.

4. Temperature gage – Dial-type thermometer, or equivalent, capable of measuring 2°F intervals from 25° to 125 °F.

5. Vacuum line – Tubing capable of withstanding a vacuum of 0.5 inch Hg absolute pressure, with "T" connection and T-bore stopcock, or equivalent.

6.   Vacuum pump – Capable of producing a vacuum of 0.5 inch Hg absolute pressure.

7.   Manometer – 36 inches Hg. with 0.1 inch divisions

8.   Squeeze bulb – One way

9.   Absorbing solution – 2.8 ml of concentrated H_2SO_4 in one liter of distilled water plus 6 ml of 3% H_2O_2, well mixed.

4.2   Sampling Procedures

Pipette 25 ml. of absorbing solution into a sample flask. Insert flask valve stopper into flask with valve in the "evacuate" position. Connect flask and pump as shown in Figure VI-2. Evacuate flask until boiling of the solution is observed. For ambient temperatures below 110°F., the absolute pressure within flask will be less than 3 inches of mercury. Turn flask valve to "purge" position. Turn pump off and check for leaks. Disconnect flask from vacuum pump. Record the volume of the flask, the temperature and the barometric pressure.

Assemble probe, squeeze bulb and flask as shown in Figure VI-3. Insert probe into sampling port and seal around probe. Purge probe and tubing using the squeeze-bulb. Turn the flask valve to its "sample" position and allow the sample to enter the flask for about 15 seconds. Turn the flask valve to "purge" position and disconnect flask. Shake flask for 5 minutes. Pack flask in protective box for transport to lab.

4.3   Sample Recovery and Sample Analysis

The procedures for sample recovery and sample analysis are given in detail under ARB Method 7.

In brief, the flask is let set for 16 hours and shaken. The pressure in the flask, the temperature and the barometric pressure are recorded. The solution in the flask is made alkaline to litmus paper with 1 N sodium hydroxide and evaporated to dryness. Phenoldisulfonic acid and sulfuric acid are added and the solution heated and stirred. The solution is cooled, diluted, made alkaline to litmus paper with concentrated ammonum hydroxide, and diluted to 100 ml. The absorbance of the sample is measured with a spectrophotometer at 420 nanometers wavelength using as a zero the absorbing solution used in sampling.
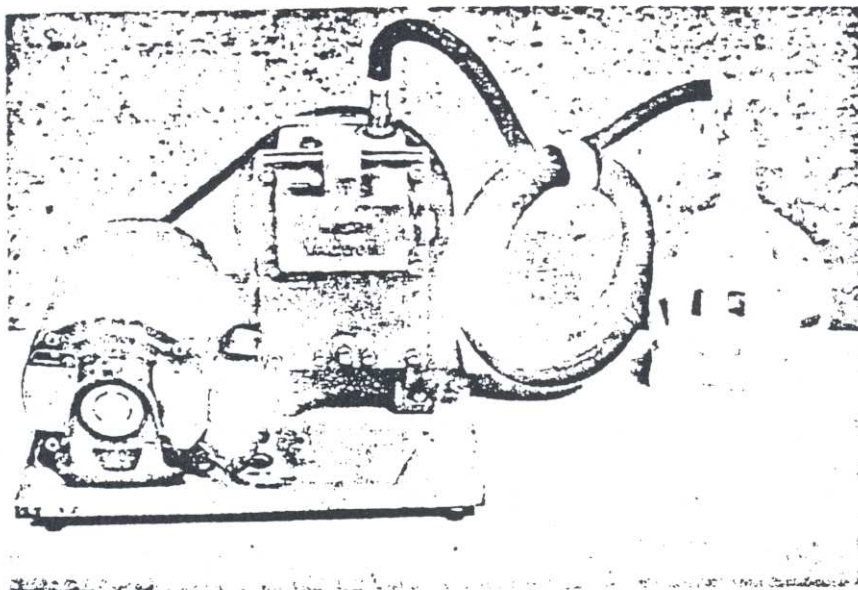
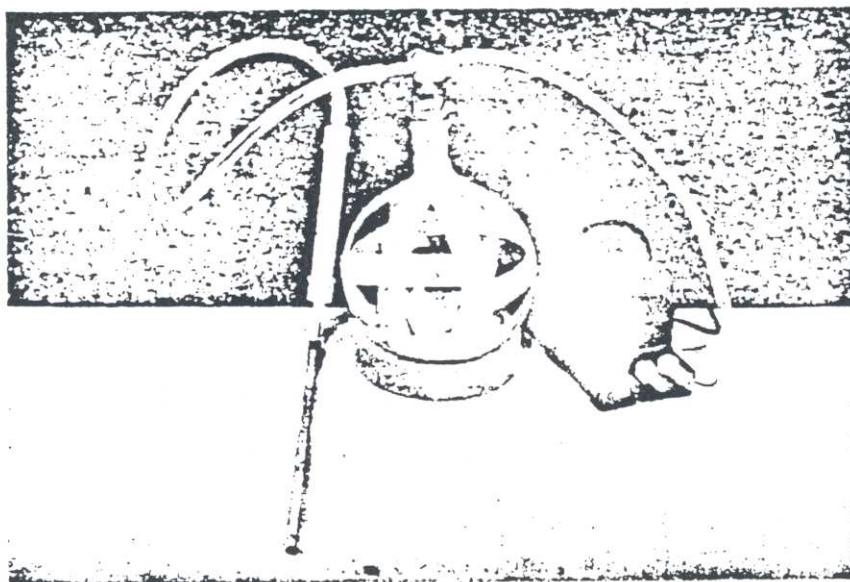FIGURE VI-2: EVACUATION OF FLASK

FIGURE VI-3: GRAB SAMPLING APPARATUS
(EVACUATION FLASK METHOD)

4.4   Calculations

The laboratory analysis is reported in micrograms of NO_2 in the sample. The test results are reported as parts per million (ppm) NO_x calculated as NO_2, in the stack gas.

Using the data from the laboratory report, calculate the test results from the equation

$$(C_{NO_x})_d = 523 \text{ x } \frac{W_{NO_x}}{V_{dg}}$$

where

$(C_{NOx})_d$ = ppm by volume as NO_2 at standard conditions

W_{NOx} = Weight of NO_x as NO_2 from lab analysis, micrograms

V_{dg} = dry volume of gas sample at standard conditions, ml.

= $\dfrac{(V_f \text{ - } 25)(p_f - pH_2O)\,528}{29.92\,T_f}$

$V_f - 25$ = Volume of gas in flask, ml.

$(p_f - pH_2O)$ = Net pressure of dry gas in flask at T_f, inches Hg.

T_f = Temperature of flask, °R.

The calculations can be done in the calculation sheet shown in Appendix VI-2. Record the calculated values in the blank lines on the sheet "Summary of Test Results" shown in Appendix X-2.

5.   CARBON MONOXIDE (CO)

Sample analysis is by non-dispersive infrared (NDIR) absorption. Sampling can be by an integrated or an instantaneous grab sample that is analyzed later in the laboratory. Alternatively, sampling can be continuous and the sample analyzed continuously in the field with a portable NDIR.

For grab sampling the probe and sample bag are as described in Section 3 of this Chapter HYDROCARBONS. An Air-cooled condenser to remove water is provided between probe and bag.

In analyzing, a sample conditioning train to remove the water vapor (H_2O) and the carbon dioxide (CO_2) in the sample are installed upstream of the analyzer. (These two substances interfere in the NDIR analysis for CO.) However, the content of H_2O and CO_2 in the stack gas must be known for the calculations. Refer to Chapter IV and V for H_2O and CO_2 measurement methods.

APPENDIX VI

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APPENDIX VI-1

State of California

AIR RESOURCES BOARD

GRAB SAMPLE LOG

Run No. _____   Operator _____

Location _____   Special Instructions _____

Sample Station _____   _____

_____

CLOCK TIME	TYPE TEST	SAMPLING METHOD	CONTAINER NO.	BAR. PRESS. (IN. HG.)	AMBIENT TEMP. (°F)

OXIDES OF NITROGEN AS NO_2 – CALCULATIONS

The dry volume of stack gas sampled is calculated as follows:

where,   #1   #2

$$V_{dg} = \frac{(V_f - V_a)(p_f - pH_2O)528}{29.92\, T_f}$$

V_{dg} = volume of dry stack gas samples, milliliters at standard conditions (68 F, 14.7 psia)

$$V_{dg_1} = \frac{17.65\, (\quad)(\quad)}{(\quad)}$$

V_f = volume of sampling flask, milliliters   ____   ____

$$V_{dg_1} = \underline{\qquad\qquad} ml$$

V_a = volume of absorbing solution milliliters   _25_   _25_

$$V_{dg_2} = \frac{17.65\, (\quad)(\quad)}{(\quad)}$$

p_f = absolute pressure in flask, inches of mercury   ____   ____

$$V_{dg_2} = \underline{\qquad\qquad} ml$$

p_{H20} = vapor pressure of water at temperature T_f, inches of mercury   ____   ____

T_f = temperature in flask, degrees Rankine   ____   ____

The calculations for oxides of nitrogen concentrations on a dry basis make use of the relation

where,

$$(c_{NOX})_d = 523\, \frac{W_{NOX}}{V_{dg}}$$

$(c_{NOX})_d$ = concentration of oxides of nitrogen (as NO_2), dry basis, parts per million by volume

$$\left(c_{NOX}\right)_{d_1} = 523\, \frac{(\quad)}{(\quad)}$$

$$\left(c_{NOX}\right)_{d_1} = \underline{\qquad} ppm$$

w_{NOX} = weight of nitrogen dioxide, from the calibration curve, micrograms   ____   ____

$$\left(c_{NOX}\right)_{d_2} = 523\, \frac{(\quad)}{(\quad)}$$

$$\left(c_{NOX}\right)_{d_2} = \underline{\qquad} ppm$$

V_{dg} = dry volume of gas sample, milliliters

$$\left(c_{NOX}\right)_{d_{avg}} = \underline{\qquad} ppm$$

____   ____

CHAPTER VII

METHODS BASED ON CONTINUOUS SAMPLING
SO_2, H_2SO_4 MIST, H_2S

1.   INTRODUCTION

In this chapter, the continuous sampling of sulfur dioxide, sulfuric acid mist, and hydrogen sulfide are each discussed.

Continuous, or integrated, sampling is employed to determine the average concentration of emissions over an extended interval of time. A representative sample of gas must be collected by proportional sampling which requires that the sampling rate be adjusted in step with or proportional to changes in the velocity of the stack gas. A pitot tube is used to indicate stack velocity and the sampling rate is adjusted accordingly as indicated on a rotameter or orifice meter.

2.   SULFUR DIOXIDE (SO_2)

This description is a synopsis of ARB Method 6, as outlined in the Federal Register. Sulfur dioxide (SO_2) is detected in the presence of sulfur trioxide (SO_3) and sulfuric acid (H_2SO_4). The latter two components are first removed by scrubbing with isopropyl alcohol. SO_2 is subsequently oxidized to SO_3 and determined by the Barium-Thorin Titration Method.

2.1   Sampling Equipment

The sampling train arrangement is shown in Figures VII-1, VII-2 and VII-3. The train consists of the following:

1)   Stainless steel or glass-lined probe, electrically heated.
2)   Glass wool filter.
3)   Four midget impingers connected in series immersed in an ice bath.
4)   Silica gel filter
5)   Gas pump
6)   Rotameter
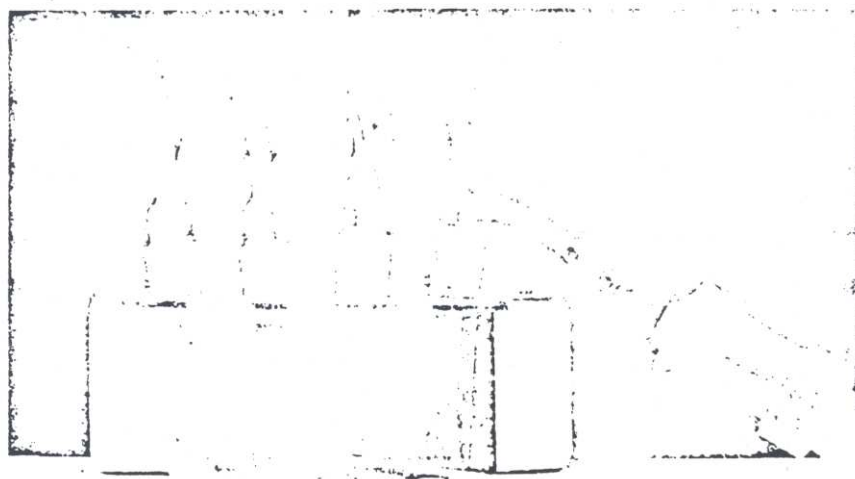7)   Dry gas meter

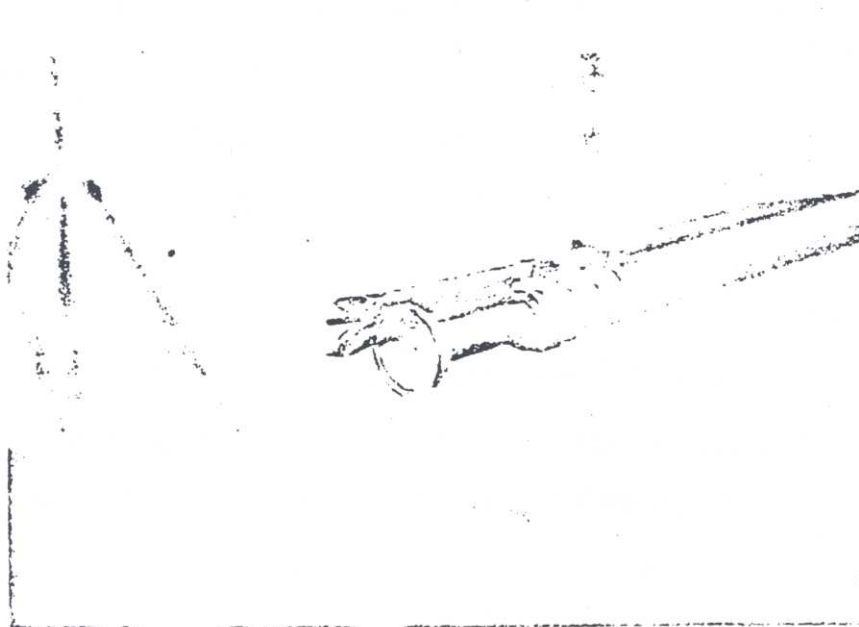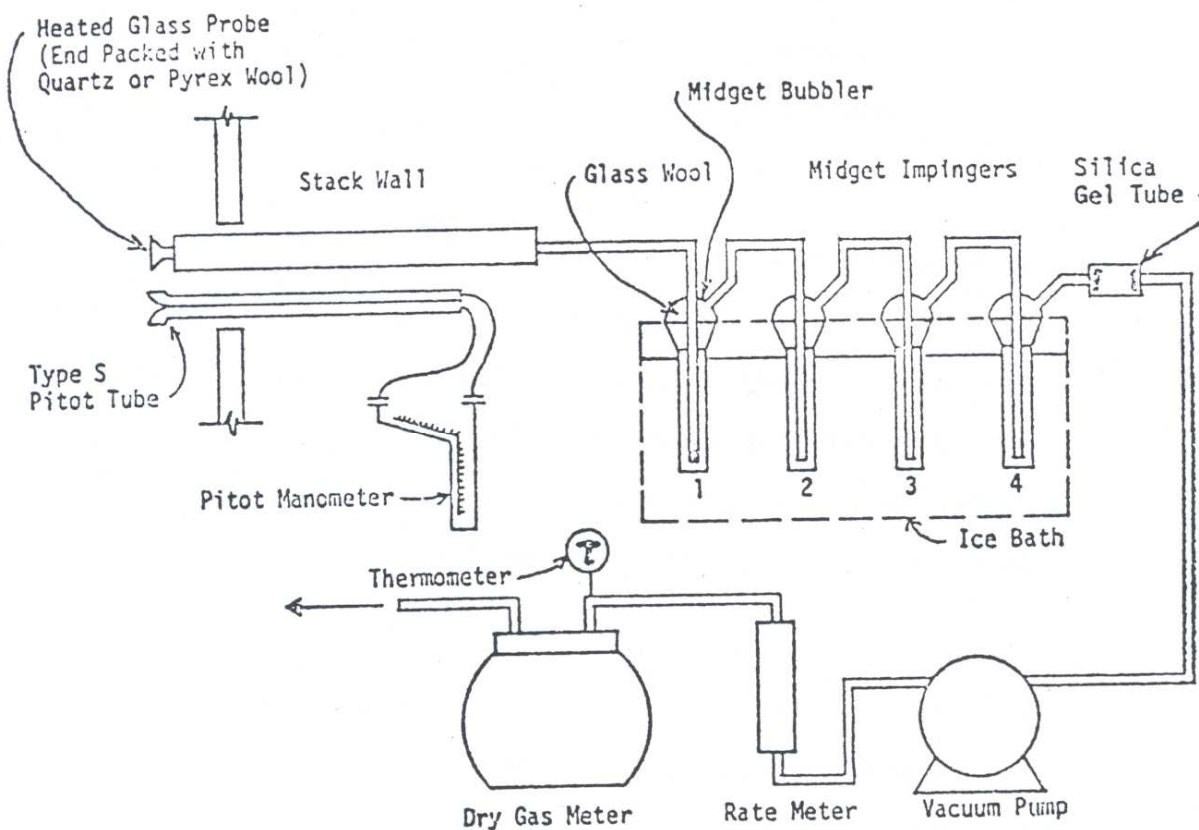FIGURE VII-1: MIDGET IMPINGER TRAIN

FIGURE VII-2: TYPICAL GLASS WOOL FILTER IN SAMPLE
LINE FOR INTEGRATED GAS SAMPLING

FIGURE VII-3: SO$_2$ SAMPLING TRAIN

LEGEND:

Midget Bubbler and Impingers
Bubbler No. 1	-	15 ML of 80% Isopropanol
Impinger No. 2 and No. 3	-	15 ML Each of 3% H$_2$O$_2$
Impinger No. 4	-	Dry

2.2   Sampling Procedure

Fill the first fritted glass-tipped bubbler with 15 ml. of 80% isopropanol. It has a glass wool plug at the top to prevent acid mist carryover into succeeding impingers. The second, third, and fourth are the standard type midget impinger. Fill the second and third impingers each with 15 ml. of 3% H_2O_2. The fourth impinger is left dry.

Leak-test the train before testing for SO_2 by capping off the probe tip and applying a vacuum of 15" Hg. to the system. A leak rate of 0.02 CFM at 15" Hg. is acceptable. Slowly release the probe's tip cap and close the pump control valve. Turn off the vacuum pump. This technique of releasing the vacuum on the system will prevent the reagent in the impingers from being drawn up into sampling probe. Add crushed ice around the impingers and maintain the impingers' final outlet temperature below 70°F.

Insert the sampling probe through the sampling port into the gas stream. Seal the opening between the sampling port and probe to prevent entrainment of outside air with the stack gases. Record the initial reading of the dry gas meter. Start the pump and stopwatch, simultaneously. The sampling flow rate is adjusted to be between 0.5 to 1.0 liters per minute. The optimum sampling rate is limited to a value which does not allow carryover of reagent into the impingers. The sampling rate is adjusted to be proportional to stack velocity. During the sampling period, take pitot, orifice and temperature readings every five minutes for an interval of one hour. Record the data on the data sheet in Appendix VII-1. At the conclusion of sampling period turn off the pump and record the final readings. Usually two one-hour samples are taken at each source. Next remove the probe from the sampling port and disconnect the probe from the impingers. Drain the water from the ice bath and purge the set of impingers with clean ambient air for 15 minutes.

2.3   Sample Recovery

Disconnect the impingers and discard the contents of the first impinger. Transfer the contents of the remaining three impingers into a 250 ml. wide mouth polyethylene bottle. Rinse the connecting glassware and tubing which is between the impingers with distilled water and pour the rinsings into the same bottle. Seal the jar and send it to the laboratory for analysis.

2.4   Sample Analysis

The weight of SO_2 in the sample is determined through titrating by the Barium-Thorin method. The method is described in EPA Method 6.

2.5   Calculations

The concentration of SO_2, by volume, on a dry basis is determined from the equation

$$C_{SO_2} = 13.27 \frac{W_{SO_2}}{V_{Mstd}} \qquad (7\text{-}1)$$

where

C_{SO_2} =   Concentration of SO_2, dry basis, ppm by volume
W_{SO_2} =   Weight of SO_2 collected, mg.
V_{Mstd} =   Volume of sampled stack gas, DSCF
          = $V_M \dfrac{P_M \bullet T_{std}}{P_{std} \bullet T_M}$

This calculation can be done on the calculation sheet shown in Appendix VII-2.

3.   SULFURIC ACID MIST AND SULFUR DIOXIDE (H_2SO_4 MIST AND SO_2)

This description is a synopsis of ARB Method 8. The weight of sample collected is used to determine the concentration of H_2SO_4 mist and SO_2 separately.

3.1   Sampling Equipment

The sample probe is shown in Figure VII-4. The sampling train is the same as the train used for particulate matter (Chapter VIII) except that the filter is located between the first and second impingers, the heated chamber is not required, and the third impinger is the standard type.

3.2   Sampling Procedure

Put 100 ml. of isopropanol in the first Greenberg-Smith impinger. Put 100 ml. of 3% hydrogen peroxide solution into each of the second and third impingers. Leave the fourth impinger empty.

From the velocity traverse described in Chapter III and the moisture determination described in Chapter IV, select the proper sampling nozzle as described in Chapter VIII. Attach nozzle.

Insert the probe into the sampling port and sample by traversing the stack as described in Chapter VIII for particulate matter. Record test data on the particulate matter test data sheet shown in Appendix VIII-2.

FIGURE VII-4: SULFURIC ACID MIST AND SULFUR DIOXIDE
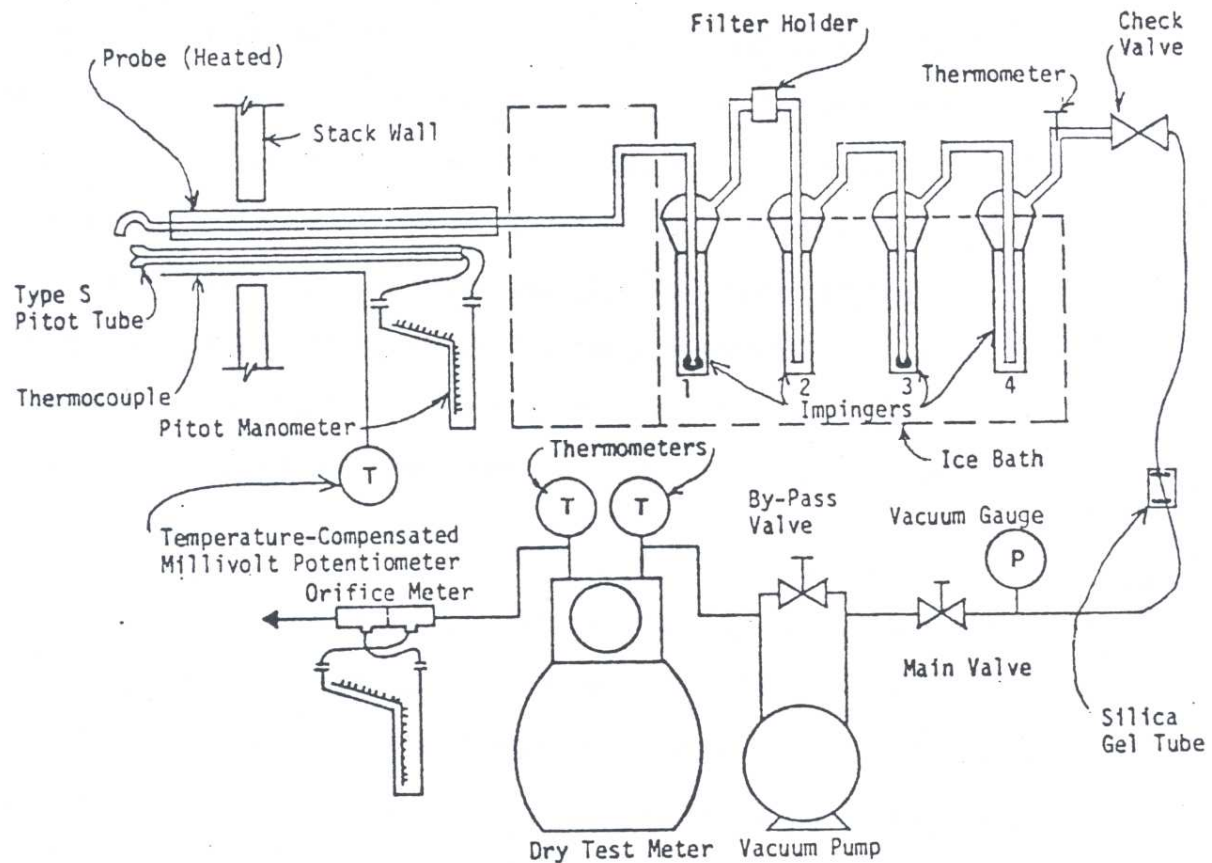
LEGEND:

Greenberg-Smith Type Impingers

No. 1 Std.	-	100 ML of 80% Isopropanol
No. 2 Mod.	-	100 ML of 3% H_2O_2
No. 3 Std.	-	100 ML of 3% H_2O_2
No. 4 Mod.	-	Dry

3.3 Sample Recovery

Disconnect the pitot tube and drain the water from the ice bath. Purge balance of the train with clean ambient air for 15 minutes. Pour the content of the first impinger into the first of two marked mason jars. Rinse the probe, first impinger and connecting glassware up to the filter holder with 80% isopropanol and pour these rinsings into the first mason jar. Place the spent filter also into the first mason jar. Transfer the contents from the second and third impingers into the second mason jar. Rinse the connecting glassware between the filter and the fourth impinger with deionized, distilled water and add these rinsings to the second jar. Seal the jars tightly and send to the laboratory for analysis.

3.4 Sample Analysis

The H_2SO_4 mist is determined from the sample in the first jar. The SO_2 is determined from the sample in the second jar. Determinations are through titrating by the Barium-Thorin Method described in EPA Methods 6 and 8.

3.5 Calculations

California APCD rules generally regulate emissions of sulfur compounds, calculated as SO_2. Therefore, calculate both H_2SO_4 Mist and SO_2 as SO_2 from the laboratory analysis results in the same manner as shown under SULFUR DIOXIDE, Section 2 of this Chapter.

4. HYDROGEN SULFIDE (H_2S)

This description is a synopsis of the ARB Method 11. The gaseous pollutants are scrubbed with cadmium hydroxide reagent which forms a cadmium sulfide precipitate.

4.1 Sampling Equipment

The sampling train is shown in Figure VII-5. This train is similar to the SO_2 sampling train.

FIGURE VII-5: H_2S SAMPLING TRAIN
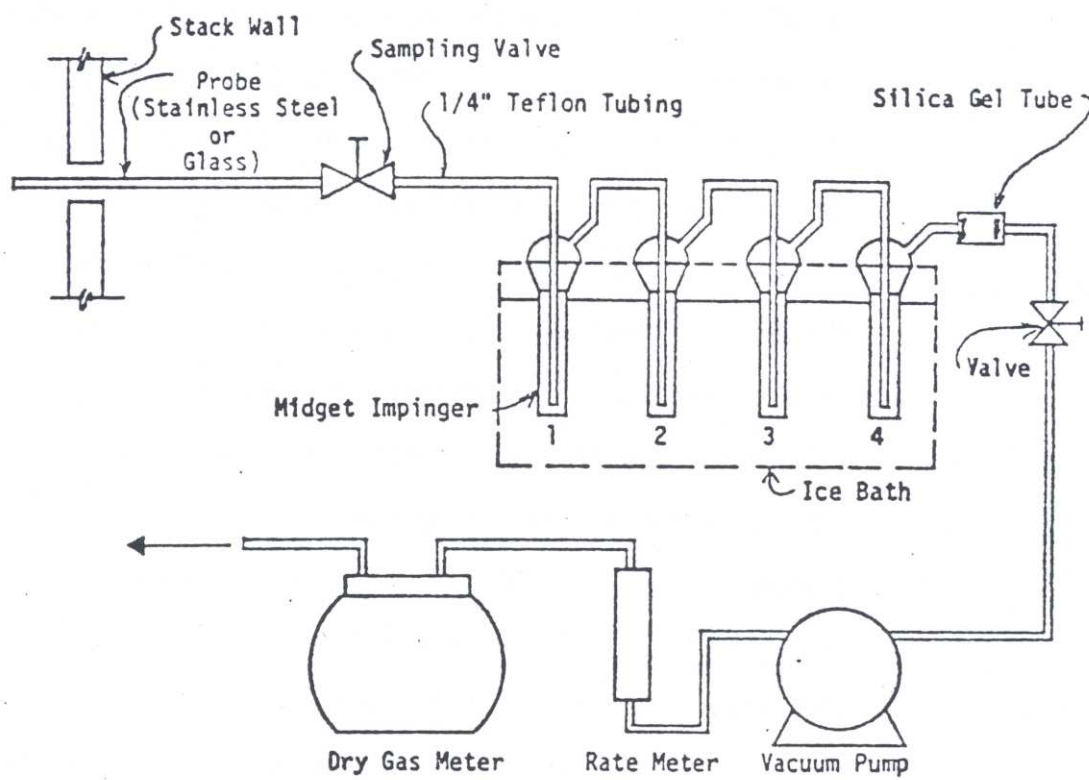
LEGEND:

    No. 1   -   15 ML Cd $(OH)_2$ Solution
    No. 2   -   Same as No. 1
    No. 3   -   Same as No. 1
    No. 4   -   Dry

4.2   Sampling Procedure

Add 15 ml. of cadmium hydroxide to each of the first three impingers and leave the last impinger empty. Use ¼" teflon tubing as the sampling probe and purge it with sampling gas. Connect the tubing to the inlet of the first impinger and record the initial reading of the dry gas meter. Turn on the pump and adjust the flow rate to one liter per minute. Record the meter volume and temperature at convenient intervals. The sampling period should be about ten minutes or should be continued until a yellow precipitate appears in the third impinger, whichever occurs first. Close the flow control valve and record the final metered volume and temperature.

4.3   Sample Recovery

At the conclusion of the sampling period, disconnect the sampling probe from the impinger train and cap the open ends of the impinger train. Take the impingers to a suitable area. Transfer the contents from all the impingers to a 500 ml., "iodine number" flask and then stopper the flask immediately. Rinse the impingers and all the connecting glassware several times with a total volume of 100 ml. of acidified iodine solution. After each rinse, stopper the impingers and associated glassware. Shake the rinsings for several moments before pouring them into the iodine flask. Allow a few minutes after each rinsing is poured into the iodine flask for absorption of the H_2S by the iodine. Continue the rinsing procedure until the 100 ml. acidified iodine solution is used up. Rinse the impingers and connecting glassware twice more with distilled water and add these distilled water rinses to the contents of the iodine number flask. The contents in the flask are analyzed at the sampling location by competent personnel.

4.4   Sample Analysis

The sulfide precipitate is dissolved in aqueous hydrochloric acid and absorbed in a known volume of iodine solution. The iodine consumed in the reaction is the measure of H_2S collected. A detailed description of the analysis is given under ARB Method 11.

4.5   Calculations

Calculate the H_2S concentration according to the equation

$$C_s = (24.97)\, \frac{W_s}{V_{m_{std}}} \qquad\qquad (7\text{-}2)$$

where

C_s = Concentration of H_2S, ppm by volume

W_s = Weight of H_2S collected, mg.

V_{mstd} = Volume of sampled stack gas, DSCF

This calculation can be done on the calculation sheet shown in Appendix VII-2.

APPENDIX VII

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File No. _____

Date _____ APPENDIX VII-1

State of California

AIR RESOURCES BOARD

DIVISION OF IMPLEMENTATION AND ENFORCEMENT

Engineering Evaluation Unit

SO_2 SAMPLING TRAIN DATA

Run No. _____ Ambient Temp. °F _____

Location _____ Bar. Press. In. Hg. _____

Sample Station _____ Operator _____

Meter No. _____ Special Instructions _____

_____

CLOCKTIME	METER VOLUME (FT^3)	METER TEMP (°F)	VACUUM (IN. HG.)	SAMPLING RATE (CFM)	ROTA-METER

SULFUR DIOXIDE AND HYDROGEN SULFIDE CALCULATIONS

File No.: _____

Date: _____

Standard Conditions: 68°F, 29.92 in Hg.
V_m Std. = Gas Volume sampled at standard conditions

<u>Sulfur Dioxide</u>

W_{sd} = Weight Collected (mg) _____, V_m = _____ cu. ft.

$$V_m \text{ std.} = 17.65 \, V_m \left(\frac{P_m}{T_m} \right) = 17.65 \, (\quad) \frac{(\quad)}{(\quad)} = \underline{\quad} \text{ scf}$$

$$\text{Concn.} = \frac{849(W_S)}{(V_m \text{Std.})}(M) = \frac{13.27 W_S}{V_m \text{Std.}} = \underline{\quad} \text{ ppm (Vol.)}$$

<u>Hydrogen Sulfide</u>

W_{HS} = _____ mg V_m = _____ cu. ft.

$$V_m \text{ Std.} = 17.65 \, V_m \left(\frac{P_m}{T_m} \right) = 17.65 \, (\quad) \frac{(\quad)}{(\quad)} = \underline{\quad} \text{ scf}$$

$$\text{Concn.} = \frac{24.97}{V_m \text{ Std.}} = \frac{24.97 \, (\quad)}{(\quad)} = \underline{\quad} \text{ ppm (Vol.)}$$

CHAPTER VIII
ISOKINETIC SAMPLING FOR PARTICULATE MATTER

1.   INTRODUCTION

This chapter describes the equipment and techniques used to sample particulate matter. Particulate matter by APCD rules includes matter which is liquid at standard conditions, and the method described accordingly can be used for this determination. The equipment is similar to that used for Test Method 5, and the particulate matter concentration by this method can also be determined.

Other methods are used for particulate sampling, such as the ASME, the ASTM, and high volume sampling. These methods are not discussed in this manual.

In particulate sampling, the velocity in the aspirating nozzle must be equal to the velocity in the stack, that is, the sampling must be done isokinetically. Errors caused by anisokinetic sampling are described in Chapter IX. The isokinetic ratio must be between 90% and 110% for the test to be acceptable. If the isokinetic ratio is outside of, but reasonably close to this range, the test results may be accepted at the discretion of the Executive Officer of the Air Resources Board. The calculation of the isokinetic ratio is shown in Appendix VIII-1.

In order that the velocity in the sampling nozzle be equal to the velocity of the stack gas, the velocity of the stack gas and its temperature must be constantly measured and the sampling rate must be adjusted. The equipment train is so designed that, with the aid of a nomograph, the adjustments can be made immediately.

The stack must be traversed during the sampling run in order to obtain an average concentration. The samples are withdrawn at the same points in the stack as are used in the velocity traverse described in Chapter III.

2.   DETERMINATION OF THE PARTICULATE CONCENTRATION

The particulate matter concentration is determined by isokinetically aspirating a measured volume of the stack gas, catching the particulate in a filter, in the probe, connecting tubing, and in the impingers, and dividing the weight of the particulate catch by the volume of gas.

For the APCD rules, matter that is liquid at standard temperature must be included. This liquid matter is assumed to pass as a gas through the filter and to then condense in the impinger water. The weight of this liquid particulate is determined by solvent extraction using methylene chloride followed by an aqueous phase extraction. Caution must therefore be used not to let any acetone or other non-water rinse enter the impinger water.

For the APCD rules, the combined weight of the particulate matter caught in the probe, the filter and the impingers is used in the determination of particulate matter concentration. For rules only the combined weight of the particulate matter caught in the probe and filter is used in the determination. Accordingly, it is advisable to report the weight of the impinger catch separately so that both the APCD and the ARB determinations can be made. The total particulate matter catch may be itemized by weight as follows: (1) Filter Catch, (2) Probe catch, (3) Impinger Catch and (4) Solvent Extract.

3.   SAMPLING TRAIN

The sampling train consists of a sampling nozzle, a heated sampling probe, a filter, four impingers, a gas pump, a dry gas meter, and a metering orifice. An S-type pitot tube is attached to the side of the sampling probe. A manometer is connected across the metering orifice to indicate flow rate. A bypass around the pump controls the flow of gas through the train by recirculating part of the capacity of the pump. Opening the valve in the bypass decreases the flow of gas through the sampling train. Maximum flow through the train occurs when the bypass valve is closed. This equipment is shown schematically in Figure VIII-1, and in a photograph in Figure VIII-2.

3.1   Nozzle

The sampling nozzle is sharp edged with smooth interior walls. It is shaped to provide minimum resistance to flow and to provide ease of entry into the sampling port in the stack. It comes in different sizes so that the desirable sampling rate and isokinetic sampling can both be achieved. The nozzle is easily detached from the probe. The selection of the correct inside diameter is discussed under SAMPLING PROCEDURE.

3.2   Probe

The probe is of metal such as stainless steel. It may be glass lined. It is wound with electrical heating tape and is insulated. The heating elements should be capable of maintaining a sampled gas temperature of 250° F (121° C) so that no condensation of water occurs. Glass lined probes are easier to clean but are subject to breakage and cannot be used for temperatures above 600° F (315° C). Furthermore, glass lined probes are non-reactive with most sampled gases. For particulate sampling, the stainless steel probe is generally acceptable and is used by the State. ARB Method 5 specifies that probes less than 8 feet in length be glass lined.

FIGURE VIII-1: PARTICULATE MATTER SAMPLING TRAIN
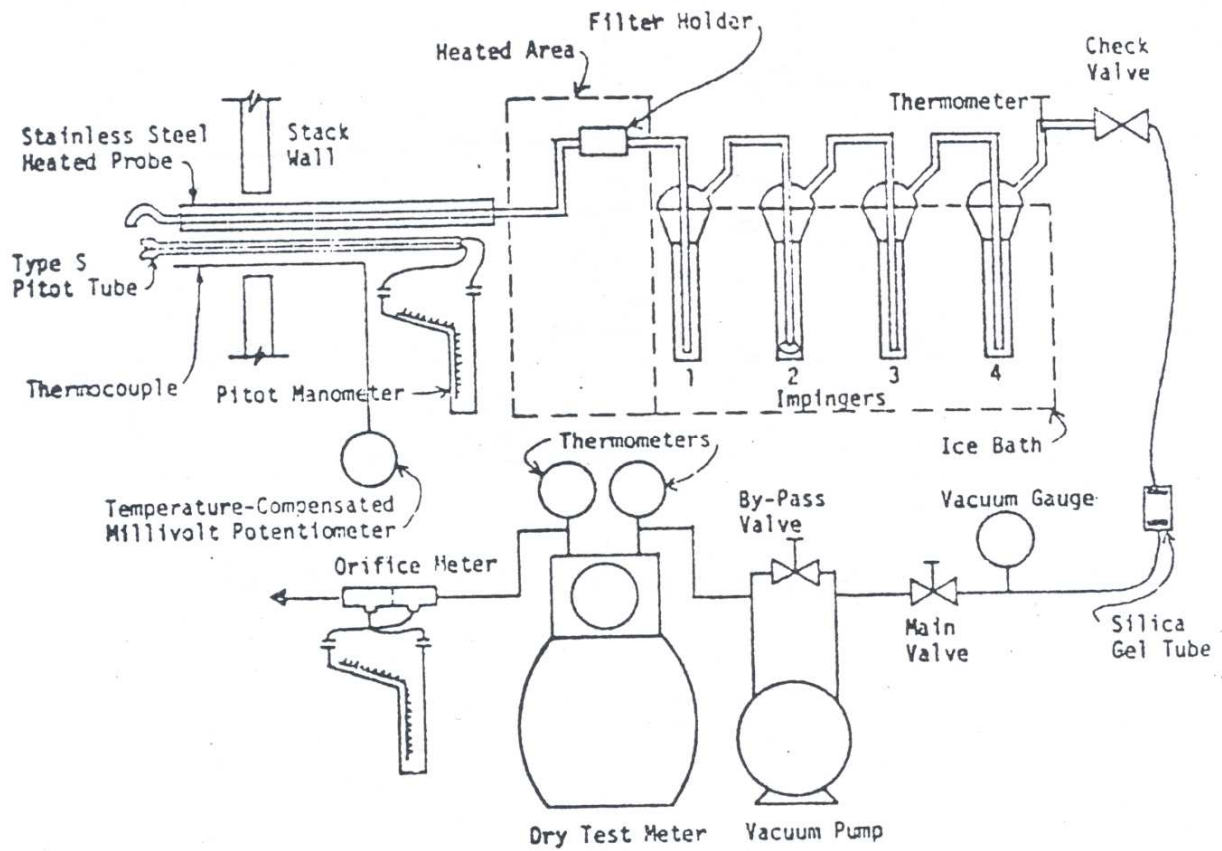
LEGEND

Greenberg-Smith Type Impingers

No. 1 Mod.   -   100 ML Deionized Distilled Water
No. 2 Std.   -   Same as No. 1
No. 3 Mod.   -   Same as No. 1
No. 4 Mod.   -   Dry

Mod.   -   Modified Type
Std.   -   Standard Type

FIGURE VIII-2: PARTICULATE STACK SAMPLER
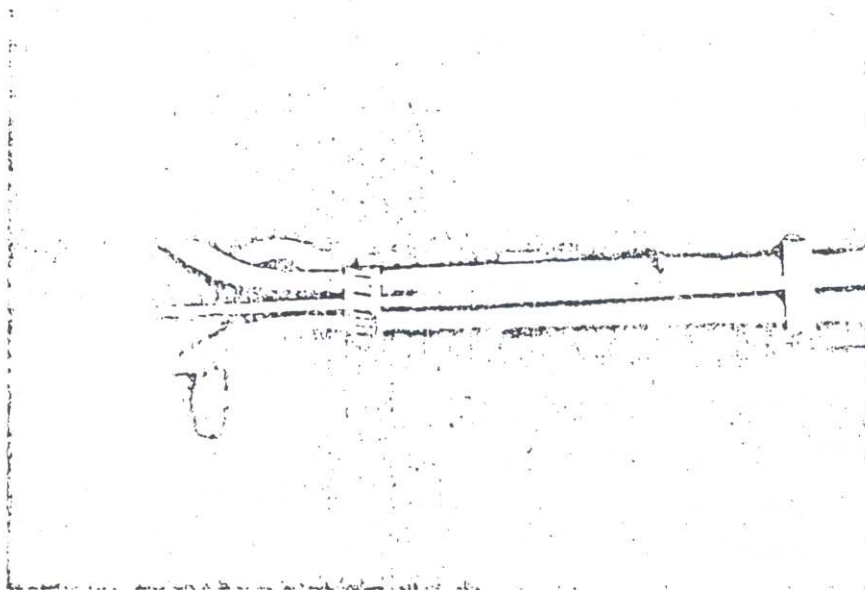
FIGURE VIII-3: PITOT TUBE-NOZZLE-PROBE ASSEMBLY

3.3   Pitot Tube

An S-type pitot tube assembly is attached to the side of the probe as shown in Figure VIII-3. The manometer for the pitot tube is located in the control cabinet. The tubing for the manometer is enclosed by the umbilical cord. The S-type pitot tube is described in Chapter III.
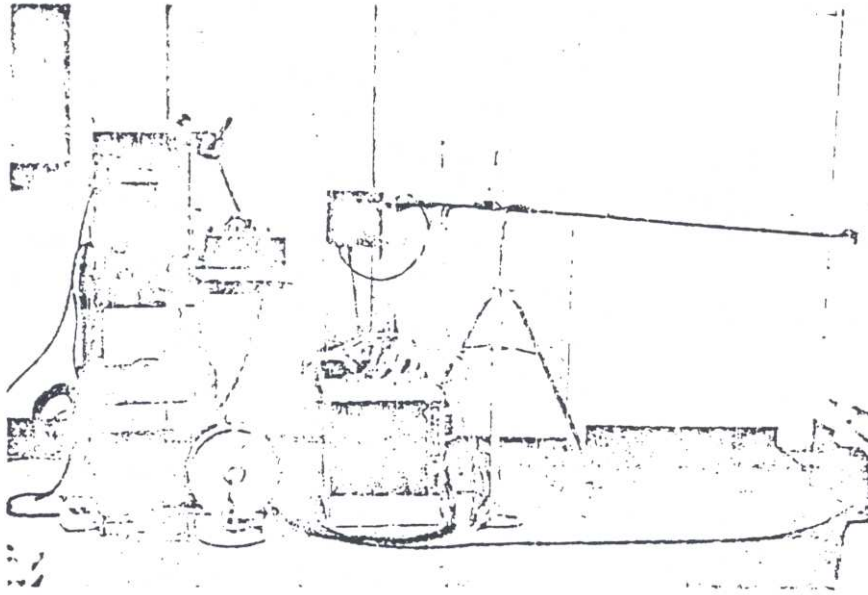
3.3.1   Proper pitot tube, sampling nozzle and thermocouple configuration to prevent aerodynamic interference.

To prevent the pitot tube from interfering with gas flow streamlines approaching the nozzle, the distance between the pitot tube and the nozzle should be at least ¾" when using a ½" inside diameter sampling nozzle. The impact pressure opening plane of the pitot tube should be even with or above the nozzle entry plane. The proper configuration between the pitot tube and the nozzle is shown in Figure VIII-4. Also shown in Figure VIII-4 is the minimum pitot-sample probe separation required to prevent interference.

The distance between the outside of the pitot tube and the thermocouple should be ¾". The thermocouple tip should be in line with the center line of the pitot tube impact opening. The proper placement of the thermocouple is shown in Figure VIII-5.

3.4   Filter

The filter should be able to withstand temperatures at least two hundred degrees above the temperature of the sampled gas. It should be 99.7% efficient for particles of 0.3 microns. The State uses MSA 1106BH or equivalent. Filters 4 inches in diameter provide the best results.

The filter is backed by a pyrex glass frit, which should provide a porous and even support for the filter paper.

The filter and its Pyrex glass holder is shown in its enclosure in Figure VIII-6. The filter holder is housed in an enclosure heated above 250° F $\pm$ 25° F (121° C $\pm$ 14° C) to prevent condensation of water on the filter.

Filter paper should be conditionally weighed and stored in a plastic petri dish and marked with the filter number, and weight. The petri dish should be retained for the sample recovery.
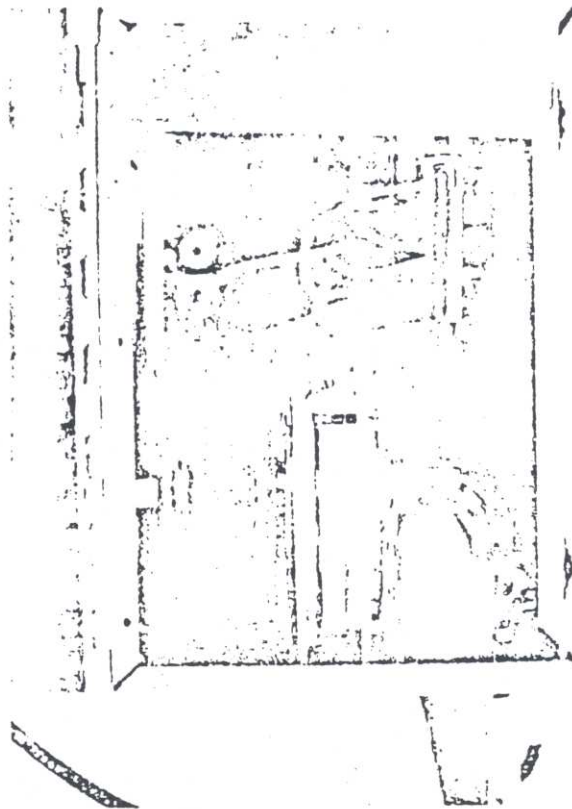
FIGURE VIII-6: FILTER HOLDER AND ENCLOSURE

3.5   Impingers

Four impingers in series follow the filter. These impingers condense the water in the stack gas, condense liquid particulate matter, and catch most of the solid particulate which has passed through the filter.

The impingers are of the Greenberg-Smith type as shown in Figure VIII-7. The first, third and fourth impingers are of the modified type as shown in the right hand side of Figure VIII-8, and the second impinger is of the unmodified type as shown in the left hand side of Figure VIII-8. The first impinger catches material which would clog the nozzle of the second impinger. The second impinger catches fine particulate matter, and the third and fourth any remaining water or particulate matter.

A silica gel drying tube follows the impinger train.

3.6   Umbilical Cord

The umbilical cord carries the sample gas line, the pitot tube tubing, the electrical heating control wiring, and 110V electrical supply, in a single casing from the sample platform to the control box, which is usually located at ground level. An umbilical cord length of fifty feet is sufficient for most applications. The umbilical cord length is limited by the ability of the pump to overcome the friction loss of the total system and still achieve the required flow rate. One hundred feet is the maximum recommended length.

3.7   Control Console

The control console encloses the instrumentation which monitors the test. Figure VIII-9 shows an RAC control console. This subsection describes the components of the control console.

3.7.1   Pump

A "leakless" vane-type pump rated at 4 cfm at 0 inches of Hg is used. The console is equipped with a bypass for the pump which can recirculate part of the flow through the pump. A valve in the bypass is therefore used to control the flow through the train. The pump is heavy and it may be advisable to take it out of the control console and mount it separately.
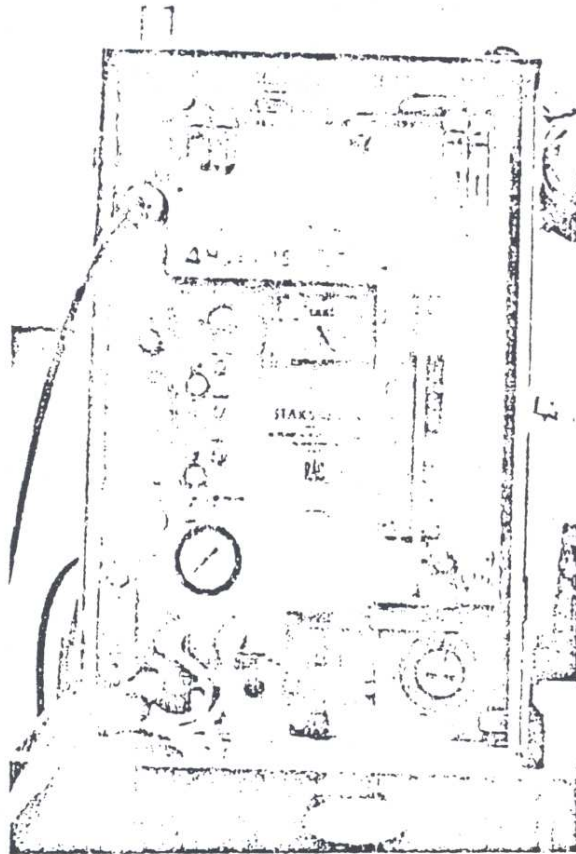
FIGURE VIII-9: METER BOX (CONTROL CONSOLE)
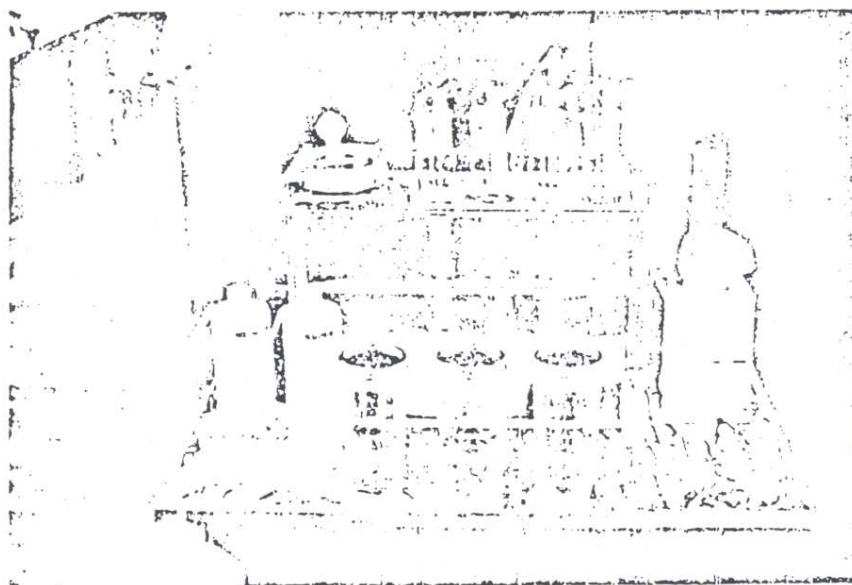
FIGURE VIII-10: SAMPLE RECOVERY ARRANGEMENT

3.7.2 Dry Gas Meter

A dry gas test meter equipped with a dial type readout and inlet and outlet dial type thermometers is used to measure the volume of the dry gas.

3.7.3 Vacuum Gage

A vacuum gage is located upstream of the bypass and main valves, the pump and the dry gas meter.

3.7.4 Metering Orifice

A calibrated metering orifice is located on the outlet side of the dry gas meter. An inclined manometer is connected across the orifice so that the sampling rate can be measured. This manometer reading is Δh of the nomograph and in data sheets in Appendices VIII-1 and –2.

3.7.5 Pitot Tube and Metering Orifice Manometers

The pitot tube manometer and the metering orifice manometer are located above one another.

3.7.6 Heater Controls

Variable voltage controls are used to maintain the probe at 250°F (121°C) and the filter box at 225°F (107°C).

4. SAMPLING PROCEDURE

4.1 Preparation for the Test

Before testing can start, preliminary measurements must be made to establish the desired sampling rate and to select the proper nozzle size.

Conduct the velocity traverse and make the calculations discussed in Chapter III. Make the moisture content determination discussed in Chapter V. Using the values so obtained, determine the nozzle size and sampling rate with the nomograph. The use of the nomograph is described in Appendix VIII-3.

A minimum nozzle size of 1/8" ID (0.32 CM) may be used but a minimum nozzle size of ¼" ID is preferable. Nozzle sizes in increments of 1/16"

(0.16 CM) should be available up to ¾" ID (1.92 CM) to meet most source sampling processes.

The procedure which follows in Sections 4.1.1 through 4.1.3 is designed specifically for the ARB-type equipment which has been modified by the ARB staff as described in Appendix VIII-4.

4.1.1 Preparation of the Collection Train

a.   Place 4 clean impingers in aluminum impinger case.

b.   Add 100 ML deionized-distilled water to each of the first two impingers. The third and fourth impingers remain dry.

c.   Interconnect impingers with vinyl tubing (1/2-in. ID x 1/8 in. wall) cut to shortest possible length without causing tubes to collapse under vacuum.

d.   Attached length of impinger-to-probe teflon tubing to first impinger. Teflon is used between the probe and first impinger because it is inert to most organic solvents and gases.

e.   Close impinger case drain valve, and add water and ice to depth of 2 to 4 inches.

f.   Assemble pre-weighed fiberglass filter disc in filter holder.

g.   Using felt tip marking pen identify each impinger and filter holder with test run number.

4.1.2 Preparation of Other Equipment

a.   After completing velocity traverse, set up probe holder.

b.   Install proper nozzle on probe (nozzle size determined from results of velocity traverse).

c.   Install probe in probe holder.

d.   Attach filter heater box to probe.

e.   Clamp filter holder to probe end ball.

f.   Cut teflon connecting tubing (Also see 4.1.1C impinger) to shortest suitable length and attach to downstream end of filter holder.

g.   Install umbilical connector on downstream stub of fourth impinger and connect to umbilical line.

h.   Leak-check assembled train by plugging nozzle and pulling 15 in. Hg. vacuum. A leakage rate of less than 0.02 cfm is acceptable.

       To prevent impinger from being forced into the filter holder at the conclusion of the leak-check, first, slowly remove the plug from the nozzle tip and then immediately turn off the pump. A leak-check shall be conducted whenever there is a modification of the sampling train during a test or between port changes.

i.   Connect manometer tubes to pitot.

j.   Connect thermocouple leads to probe and impinger thermocouples.

k.   Connect electrical leads from umbilical to heater box, and attain grounding cable from the probe to nearest suitable ground.

l.   Turn on console switches for filter heater box and probe heater.

m.   Pre-heat filter and probe for 25 minutes.

n.   Add crushed ice to impinger case.

4.1.3 Testing Procedure (For trouble shooting see Appendix VIII-5)

a.   Insert probe in the stack at the first traverse point with nozzle pointed directly into the gas stream.

b.   Record the initial gas meter reading.

c.   Start the vacuum pump, and adjust the flow to isokinetic conditions as determined with the nomograph.

d.   Sample for at least 2 minutes at each traverse point. Sampling time must be the same for each point. Record the data on the field data sheet in Appendix VIII-2.

e.   Maintain isokinetic conditions throughout the test by adjusting the flow rate for changing stack gas velocities and temperatures.

f.   At the conclusion of the test run, turn off the pump and then turn off the main console.

g.   Shut off probe heater and filter heater box switches.

h.   Record the final gas meter reading.

4.1.4   Post-Test Procedures with Equipment

After the test is finished, the following steps must be taken with the equipment:

a.   Remove the probe from the sampling port.

b.   Make post test leak check.

c.   Disconnect the umbilical, manometer tubes and thermocouple leads.

d.   Remove probe and train to sample recovery area. (See Figure VIII-10)

4.1.5   Recovery of Sample from Probe and Nozzle

a.   Allow probe to cool before rinsing.

b.   Handle probe carefully to prevent loss of particulate matter in probe.

c.   Clean loose particulate matter from external sources of probe adjacent to the two ends.

d.   Remove nozzle and rinse inside surfaces with deionized-distilled water and acetone or other suitable solvent. Use a small bristle brush or rubber policeman to clean any particles remaining after rinse. Collect rinsings in sample jar.

e.   Cleaning the probe is generally a two-man job, with one man with squeeze bottle at one end of probe and the second man at other end of probe holding a sample jar to catch the rinse liquid.

f.   Rinse the probe with deionized-distilled water or acetone to remove large particles. Slowly rotate probe during rinse.

g.   Run a gun bore brush through the probe. Rinse the brush. Then withdraw the brush and rinse both the brush and the probe again.

h.   Collect all rinsings in a sample jar and label the jar with the identification number and date.

4.1.6 Recovery of Sample from Filter Assembly

a.   Remove the retaining nuts and separate the two filter halves with the filter disk side up.

b.   Carefully remove the filter disk from the supporting glass frit, and place in its plastic petri dish. Cover dish and seal with masking tape. Important: store petri dishes with particulate side of filter disk up. Label the petri dish with respect to the corresponding test identification number and date.

c.   Scrape residual filter material from silicone seal and add to petri dish.

d.   Rinse the upstream half of filter and add rinse water to the sample jar containing the probe rinse. Use a rubber policeman or s.s. spatula to remove material not removed by rinsing.

e.   Rinse the downstream half of the filter assembly and support frit and add to the impinger rinse.

4.1.7 Recovery of Sample from Impingers and Connecting Tubing

a.   Rinse the teflon tubing which connects the downstream half of the filter assembly to the first impinger with methylene chloride. Collect the rinsing in a sample jar.

b.   Remove the tygon tubing from the impinger stubs by cutting tubing lengthwise over the stubs.

c. Rinse each tube length with deionized-distilled water and collect the rinse water in a sample jar.

d. Remove the impingers from the impinger case and place in rack.

e. Starting with the No. 1 impinger, wipe the dust from its stopper to prevent external dust from falling into the impinger flask during the removal of the stopper.

f. Withdraw the stopper carefully from the flask.

g. Rinse all surfaces of stopper exposed to gas streams with deionized distilled water and collect rinsings in sample jar.

h. Wipe the silicone grease from the flask ground joint using a kimwipe moistened with a acetone or freon precision cleaning agent (PCA).

i. Pour the contents of the No. 1 flask into a graduated cylinder. (Record the volume)

j. Rinse flask with deionized-distilled water, and with methylene chloride to dissolve oil or resins and collect rinsings in sample jar.

k. Repeat steps e thru j on the remaining 3 impingers.

l. Rinse each length of connecting tubing with deionized-distilled water only.

m. Record net amount of condensed water collected as measured in graduated cylinder, and add to sample jars.

n. Label each sample jar with test identification number and date.

4.1.8 Triplicate Sampling Run

a. Repeat steps in Sections 4.1.1 through 4.1.7 to provide triplicate particulate matter sample.

4.1.9 Deliver all sample jars and filters to the laboratory.

5   CALCULATIONS

   5.1   Isokinetic Variation

       a.   From information on the field data sheet in Appendix VIII-2,
             calculate the isokinetic variation for each sampling run as shown in
             Appendix VIII-1. This can be done in the field immediately after
             each source test. If the test is not within the isokinetic variation, it
             gives an opportunity to retest while still in the field.

   5.2   Emissions

       a.   From the laboratory analysis results, the field data, and the flow
             rate calculated in Chapter III, calculate the particulate matter
             concentration in the stack gas and the emission rate as shown in
             Appendix VIII-1. The reported particulate matter concentration and
             emission rate will be the average of the three sampling runs.

6.   SAMPLE ANALYSIS

   The laboratory procedures for analyzing test samples for particulate matter
   generally include the following steps.

   The filter catch is determined by weighing.

   The impinger rinsings are extracted with a solvent that is not miscible with water
   to separate the oil and resinous materials. The weight of these materials is
   determined. These materials would become liquid droplets at standard
   conditions and are included as particulate matter in most California APCD
   regulations.

   The water fractions of the rinsings from upstream and downstream of the filter
   are separately evaporated to dryness at 105°C in tared evaporating dishes. The
   probe catch and the impinger catch are determined.

   These results are reported on a standard laboratory form that lists separately the
   filter catch, the probe catch, the impinger catch of solid particulate matter, and
   the impinger catch of liquid particulate matter.

APPENDIX VIII

TABLE OF CONTENTS

File No. _____

State of California

AIR RESOURCES BOARD

Division of Implementation & Enforcement – Engineering Evaluation Unit

PARTICULATE SAMPLING CALCULATIONS

Standard Conditions 60°F @ 29.92 in. Hg (Dry Basis)

A.   Material Collected (M_n)

_____

_____

_____

_____

_____

_____

                                                   Total _____ mg.

B.   Concentration (C'_s)

$$C'_s = .0154 \, \frac{gr.}{mg} \bullet \frac{M_n}{V_{mstd}} = .0154 \frac{(\quad\quad\quad)}{(\quad\quad\quad)} = \underline{\quad\quad\quad} \; gr./SDCF$$

C.   Emission Rate (M_m)

$$M_m = .00857 \, C'_s Q_s$$

$$M_m = .00857 \, \frac{min/hr}{gr./lb.} (\quad\quad) (\quad\quad) = \underline{\quad\quad\quad} \, lb/hr.$$

ISOKINETIC VARIATION

D.   Total Volume of Stack Gas (V_{tstd})

$$V_{mstd} = \underline{\quad\quad\quad} SCF \quad\quad V_{wvstd} = \underline{\quad\quad\quad} SCF$$

$$V_{w_{std}} = \left[\frac{B_{wo}}{1 - B_{wo}} \right] \left[V_{m_{std}} \right] - V_{wv_{std}} = \frac{(\quad\quad\quad)}{(\quad\quad\quad)} (\quad\quad) - (\quad\quad) = \underline{\quad\quad\quad} SCF$$

$$V_{t_{std}} = V_{m_{std}} + V_{w_{std}} + V_{wv_{std}} = (\quad\quad) + (\quad\quad) + (\quad\quad) = \underline{\quad\quad\quad} SCF$$

E.   Percent of Isokinetic Sampling (I)

$$I = \frac{v_n}{v_s} \times 100 = \frac{\left[V_{tstd}/(60\,\theta\,A_n)\right]\left[(T_s/P_s)\times(P_{std}/T_{std})\right]}{v_s} \times 100$$

$$I = \frac{17.58\ V_{tstd}T_s}{(D_n)^2\,\theta\,P_s\,v_s} = \frac{(17.58)(\quad\quad)(\quad\quad)}{(\quad\quad)(\quad\quad)(\quad\quad)(\quad\quad)} = \rule{2cm}{0.4pt}\%$$

APPENDIX VIII-2

PARTICULATE FIELD DATA

Ambient Temp °F _____

Run No. _____   <u>VERY IMPORTANT</u> – <u>FILL IN ALL BLANKS</u>   Bar. Press. "Hg _____

Location _____   Read and record at the start of each test point.   Assumed Moisture % _____

Date _____   Heater Box Setting, °F _____

Operator _____   Probe Tip Dia., In. _____

Sample Box No. _____   <u>LEAK CHECK</u>   Probe Length _____

Meter Box No. _____   <u>BEFORE</u>   <u>AFTER</u>   Probe Heater Setting_____

Pitot Tube Factor _____

Point	Clock Time	Dry Gas Meter, CF	Pitot in. H$_2$O ΔP	Orifice ΔH in H$_2$O		Dry Gas Temp. °F		Pump Vacuum In. Hg Gauge	Impinger Temp °F	Stack Press In. Hg	Stack Temp. °F
				Desired	Actual	Inlet	Outlet				

APPENDIX VIII-3

USE OF NOMOGRAPH

1.   INTRODUCTION

The nomographs shown in Figures A and B are designed for use with the EPA particulate sampling method. The nomographs are designed to determine the nozzle size, and the metering orifice pressure differential (Δh) for a given velocity head (ΔP) of the stack gas. Isokinetic sampling is achieved by the correct use of the nomograph.

The correction factor nomograph shown in Figure A is used and determines a factor "C" to be used in the operating nomograph.

The operating nomograph shown in Figure B is used to determine the nozzle diameter and subsequently to determine the metering orifice differential pressure (Δh) for the measuring stack gas velocity heads (ΔP).

2.   USE OF THE CORRECTION FACTOR NOMOGRAPH

The correction factor "C" is determined by using the correction factor nomograph. The following parameters must first be found:

$$T_m \quad = \quad \text{Meter Temperature } °F$$

$$P_m \quad = \quad \text{Meter Pressure (in. Hg Absolute)}$$

$$P_s \quad = \quad \text{Stack Gas Pressure (in. Hg Absolute)}$$

$$\% H_2O \quad = \quad \text{Moisture content of stack gas (\%)}$$

The value of Δh @ must also be known for the desired flow rate. This value is supplied by the manufacturer and can also be determined by calibration. Usually a flow rate of 0.75 cfm is desired.

After the parameters have been established, a value for "C" can be obtained by following these three steps"

a.   Draw a line from Δh @ to T_m and obtain Point A on Reference 1.

b.   Draw a line from Point A to % H_2O and obtain Point B on Reference 2.

FIGURE A – CORRECTION FACTOR NOMOGRAPH

ORIFICE READING
ΔH

C
CORRECTION FACTOR

K FACTOR

PITOT READING
ΔP

T.
STACK TEMP.

PROBE
TIP DIA.
D

ΔH = in. H₂O
C = dimension-less
T. = °F
K = dimension-less
D = in.
ΔP = in. H₂O
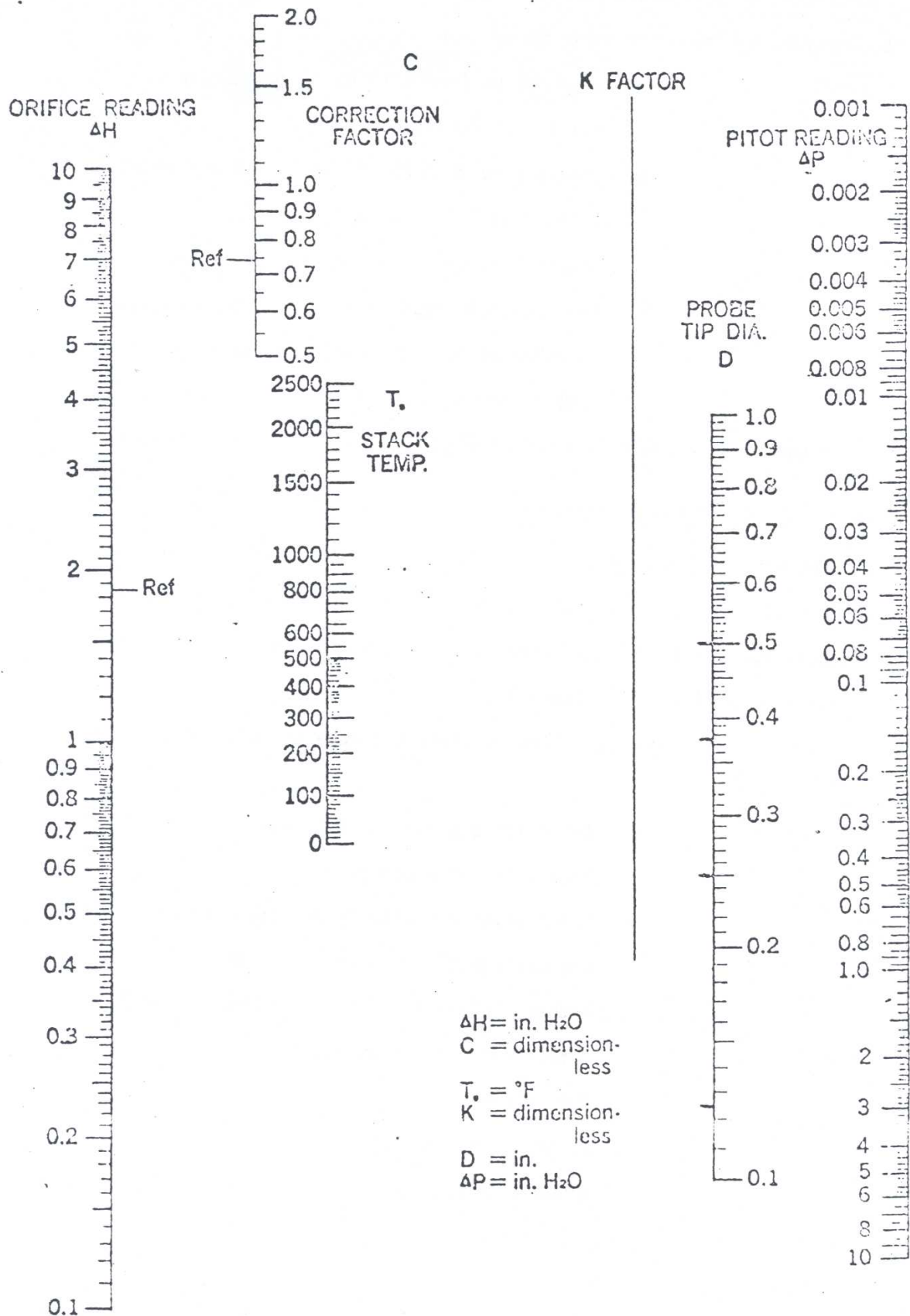
      c.   Draw a line from Point B to P_s/P_m. At intersection, read value of "C" on C scale. (A value of P_m can be obtained from the preliminary moisture run).

A numerical example is shown on Figure A.

3.   USE OF THE OPERATING NOMOGRAPH

The operating nomograph is used to obtain a new orifice differential pressure value (Δh) for adjusting the isokinetic flow rate when changes in stack velocity or ΔP have occurred. It can also be used to obtain the correct nozzle size. See Figure B.

Prior to sampling the following steps are made to obtain the "K" factor or pitot point:

      a.   Set sliding scale so that the "C" factor is in line with reference point.

      b.   Align pivot arm with T_s and the average, maximum and minimum ΔP obtained in the preliminary velocity probe. Select a probe tip diameter (nozzle size) from the D scale that most closely satisfies the ΔP values.

      c.   Align the pivot arm with T_s and the probe tip diameter selected. Obtain a pitot reading from the ΔP scale.

      d.   Align the pivot arm with the ΔP value obtained from Step C and the Reference mark on the Δh scale.

      e.   Lock the pivot arm in place.

      f.   Check desired Δh values for maximum and minimum ΔP values. If recommended sampling rate is exceeded, ($0.3 < \Delta h < 6$), two separate nozzles might have to be used.

      g.   During sampling, determine Δh from given ΔP. Adjust sampling rate accordingly.

      h.   If there is a significant change in T_s ($25°F$ for $T_s < 1000°F$ or $50°F$ for $T_s > 1000°F$), or if the nozzle is changed, a new K factor will have to be set on the nomograph.

APPENDIX VIII-4

STACKSAMPLER MODIFICATIONS

Modifications have been made to RAC STAKSAMPLER by the ARB to enable easier handling and to facilitate the train assembly at the test site.

1.   The pump has been installed in a separate carrying case.

2.   The filter, including the heater box, has been detached from the impinger box and is attached to the downstream end of the probe.

3.   Since the EPA tests do not require the use of a cyclone upstream from the filter, the cyclone has been removed.

4.   Heavier wires with better insulation have been substituted for the original wiring provided with the STAKSAMPLER.

5.   Each impinger box supplied with the train contained one set of impingers. ARB now uses a larger impinger box containing two sets of impingers.

6.   The heating system on the probe has been modified to enable the easy removal of the probe heater tape.

7.   Equipment has been added including a probe holder, a tripod probe support, and a boom to assist in lifting the heavier pieces of equipment to the sampling sites. A male threaded fitting for a 3" coupling has been added to support the pitot tube and probe in the sampling port.

8.   An electrical grounding cable has been added to connect the probe to nearest suitable ground, and ground fault circuit interrupters are connected to all power sources.

TROUBLE SHOOTING SOURCE SAMPLING TRAINS

Symptom	Possible Cause	Correction
1) Loss of Pitot Tube Reading	a) Kink in Line	Straighten Line
	b) Condensate in Line	Remove Line and Expel Condensate
	c) Plugged Pitot Tube	Blow Out Pitot Tube
	d) Air Bubble in Manometer	Remove Bubble
	e) Dirty Manometer	Remove and Clean
2) Negative Pitot Tube Reading	a) Sampling Nozzle Not Parallel to Gas Flow	Correct Position
	b) Obstruction in Stack	Make Appropriate Change
	c) Pitot Tube Lines Crossed	Reverse Lines
	d) Control Box Not Level	Relevel and Rezero Manometer
3) Fail to Maintain Isokinetic Sampling	a) Abnormal Loading Filter Disk	Terminate Sampling and Replace Filter
	b) Moisture Saturated Filter	Terminate Sampling and Replace Filter
	c) Loose Connection	Check for Leak and Retighten Connection
	d) Collapsed Tubing	Replace with Heavier Walled Tubing
	e) Defective Vacuum Pump	Replace Pump
	f) Vacuum Gage Reading Erratic.	Replace Vacuum Pump or Gage
	g) Incorrect Nozzle Size	Recheck Nomograph Settings and Replace with Correct Size
	h) Defective Dry Gas Meter	Replace Meter
	i) Control Valves Incorrectly Set	Check Setting and Adjust Accordingly
	j) Pivot Point on Nomograph Moved	Recheck and Adjust Accordingly
	k) Upset Condition in Process	Stop Sampling, Resume Sampling After Upset Condition is Corrected.

CHAPTER IX

ERRORS IN PARTICULATE SAMPLING

1.   INTRODUCTION

Experiments and theory show that significant errors will occur if particulate matter sampling is not conducted isokinetically. For isokinetic sampling, the gas velocity in the sampling nozzle must be equal to the gas velocity in the stack. Errors will also occur if the sampling nozzle is not aligned with stack gas flow, and if the sampling nozzle diameter is less that one quarter inch. Another error may occur if the stack is not traversed during the sampling.
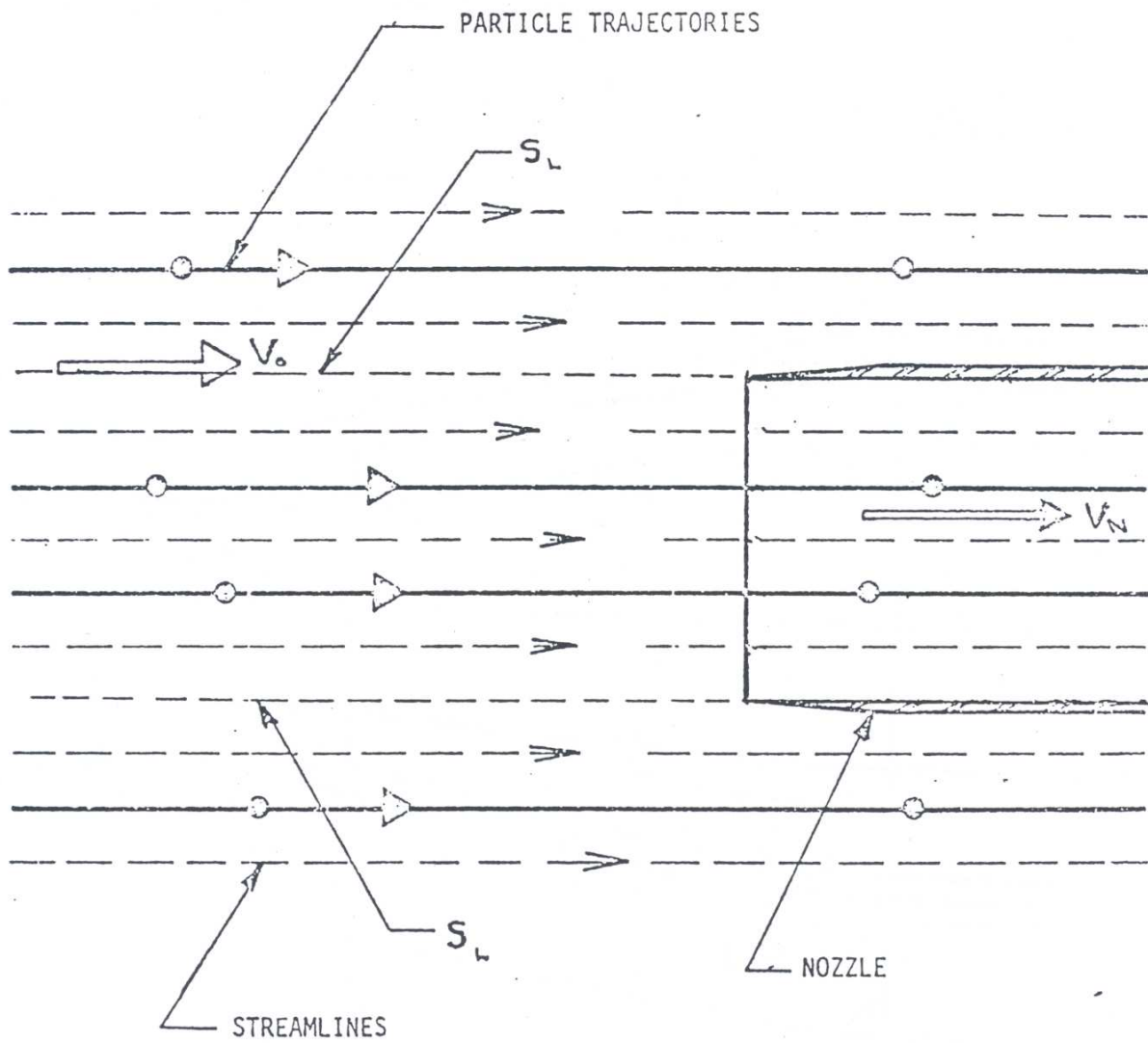
2.   ISOKINETIC SAMPLING

Consider a nozzle inserted in a dust-laden gas stream in Figure IX-1. In this case the velocity of gas in the sampling nozzle is equal to the velocity of the main stream. If the wall of the nozzle is thin and the entry is tapered to a knife edge, then the streamlines of gas flow (dotted lines) will remain parallel straight lines. The airborne particles will also remain in straight lines. All of the particles in an imaginary cylinder of air bounded by the limiting streamlines S_L will enter the nozzle. Therefore, the concentration of particulate matter in the air stream entering the nozzle will be the same as the concentration in the mainstream. Accordingly, isokinetic sampling introduces no error.

3.   OVER-ISOKINETIC SAMPLING

Consider the next case, as shown in Figure IX-2, in which the nozzle velocity is greater than the velocity of the main stream. Again, the dotted lines are the streamlines of the gas flow and the streamlines S_L are the limiting streamlines of the gas entering the nozzle. The datum line L is the limit of the upstream disturbance caused by the nozzle. The gas within the streamlines not only changes direction but also increases in velocity as it approaches the nozzle. The shape of the streamlines is such that the flow of gas at the line L and bounded by the limiting streamlines S_L is equal to the flow of gas through the nozzle. The particles of dust conveyed by the gas stream have a velocity close to that of the gas stream. However, the mass of the particles is very much greater than that of the molecules of gas and therefore the particles obey Newton's law of motion and tend to continue in a straight line.

Consider particles that have the same size and density. At datum line L, particle A is within the limiting streamlines S_L and therefore should enter the nozzle, if sampling is to be correct. It will tend to continue in a straight line but is deflected toward the nozzle because of the influence of the streamlines. These streamlines will accelerate the particle both radially and axially. The trajectory

FIGURE IX-1: ISOKINETIC SAMPLING

$$V_N = V_O$$

$V_N > V_O$
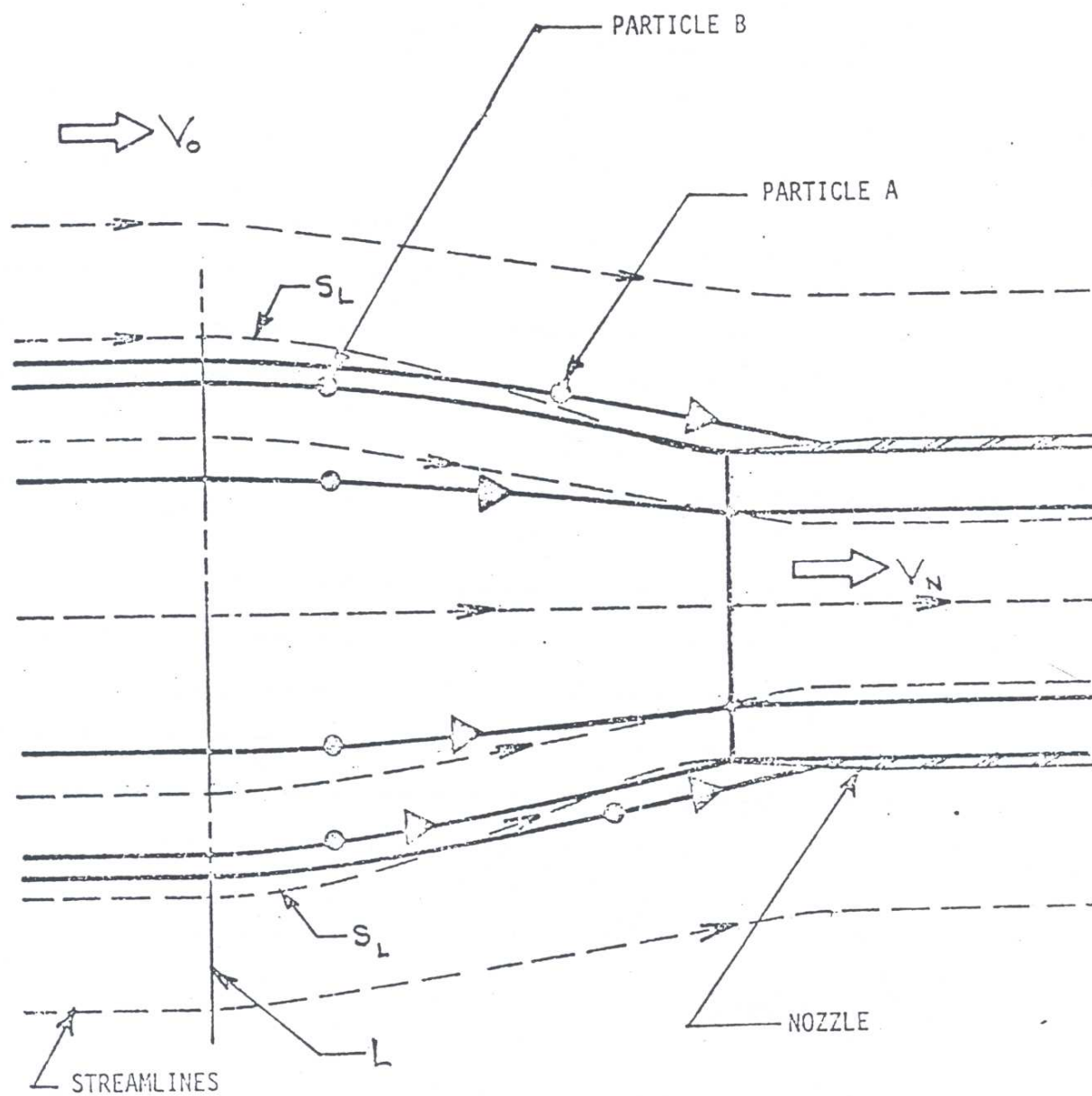
FIGURE IX-2: OVERISOKINETIC SAMPLING

for particle A crosses over the limiting streamlines S_L and does not enter the nozzle.

Particle B has a trajectory which contracts the edge of the nozzle and the particle has a fifty percent chance of entering the nozzle. The trajectory of particle B is the limiting trajectory for particles of this size and density entering the nozzle. All particles of this size and density within the limiting trajectory will enter the nozzle and none of the particles outside of the trajectory will enter. The error in the sampled concentration will be the area of the annulus at datum line L bounded by the limiting trajectory and the limiting streamlines S_L divided by the area of the circle bounded by the streamlines S_L.

The limiting trajectory is dependent on:

1. The diameter of the particle

2. The density of the particle

3. The drag coefficient of the particle

4. The velocity of the stack gas

5. The viscosity of the stack gas

These parameters are consolidated into two other parameters, one of which is the Reynolds number and the other is called the particle inertia parameter. For a given stack gas stream and nozzle, the particle diameter is the controlling parameter. Large particles will have little deflection from their original path and will accordingly cause the largest error. Very small particles will closely follow the streamlines and will have small error. The sampled concentration for all sizes of particles has an error on the low side when the nozzle velocity is higher than the stack velocity, that is, when the isokinetic ratio in your calculations is greater than 100%.

4.   UNDER-ISOKINETIC SAMPLING

The situation when the nozzle velocity is less than the main stream velocity is shown in Figure IX-3. The streamlines diverge in this case because the gas velocity is decreasing. The streamlines S_L are the limiting streamlines to enter the nozzle. The datum line L is the limit of the upstream disturbance caused by the nozzle. The shape of the streamlines is such that the flow of gas past the datum line L and bounded by the streamlines S_L is equal to the flow of gas through the nozzle. All of the particles within the streamlines S_L should enter the nozzle and none outside should enter, if sampling is to be correct.
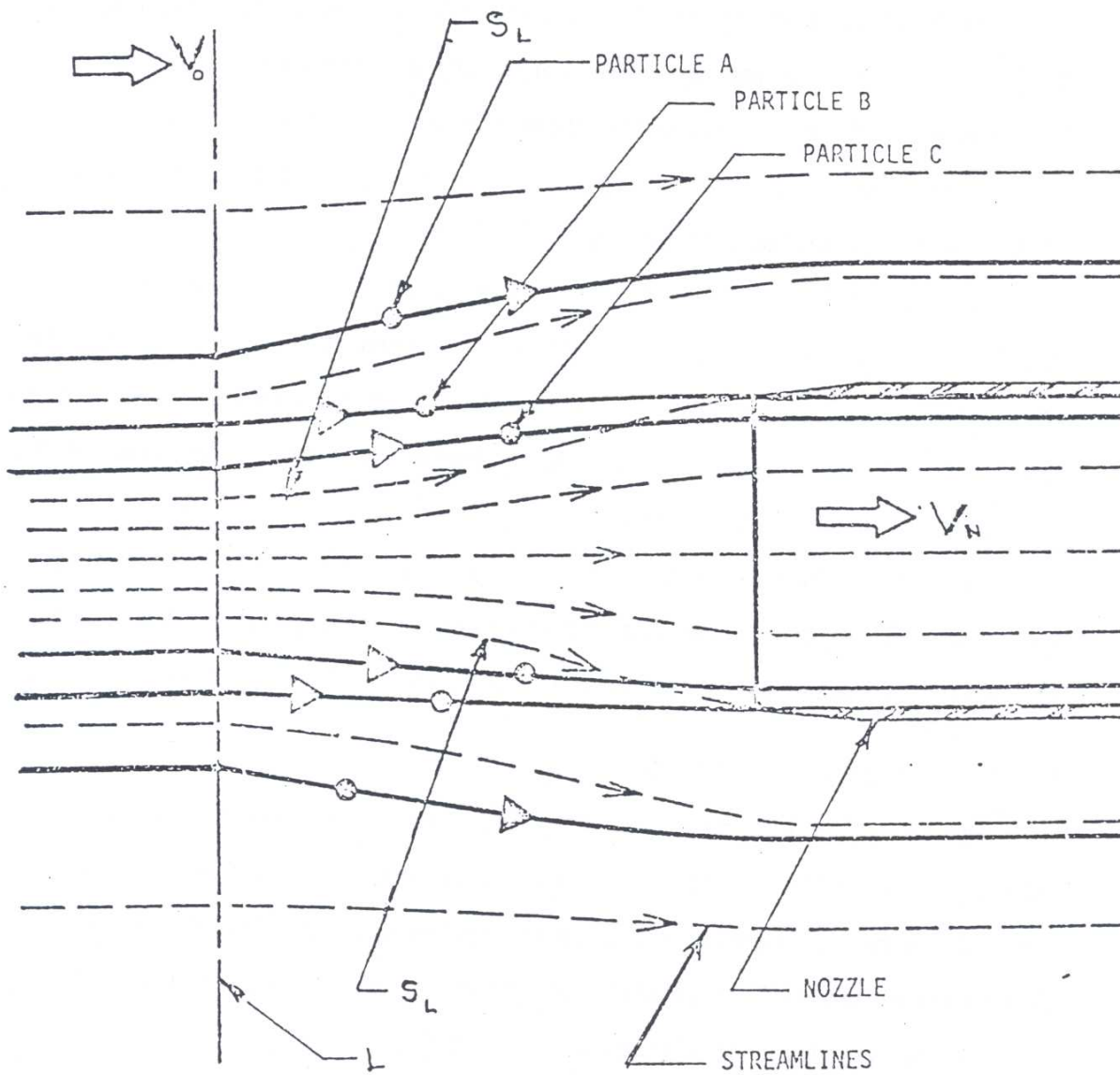
$V_N < V_O$

FIGURE IX-3: UNDERIOSKINETIC SAMPLING

Consider particles that have the same size and density. At datum line L, particle C is outside of the envelope bounded by the streamlines S_L and should not enter the nozzle. This particle, because of its inertia, tends to follow a straight line but is subject to a radial accelerating force and an axial decelerating force from the streamlines. The radial accelerating force is not great enough to deflect the particle sufficiently. The particle's trajectory crosses the limiting streamlines S_L, and enters the nozzle.

The particle B is further than particle C outside of the envelope bounded by the streamlines S_L. The trajectory of this particle coincides with the edge of the nozzle and is therefore the limiting trajectory. All of the particles outside of this trajectory will not enter the nozzle and all of the particles inside will enter.

Since particles outside of the limiting streamlines are entering the nozzle, the sampled concentration will have an error on the high side. The magnitude of the error will be the area of the annulus at datum line L bounded by the streamlines S_L and the limiting trajectory divided by the area of the circle at L bounded by the streamlines S_L.

For a given nozzle and gas stream, the limiting trajectory for large particles will be nearly parallel to the axis of the nozzle and the limiting trajectory for small particles will be close to the limiting streamlines S_L.

5.   MAGNITUDE OF ERRORS IN ANISOKINETIC SAMPLING

The theory of isokinetic sampling led many investigators to conduct experiments to determine the errors caused by anisokinetic sampling and to develop theoretical methods for determining the errors. All of the investigators found that errors will occur that confirm the theory. For example, the sampling of 12 micron particles of silicon carbide at 50% isokinetic caused the sampled concentration to be 80% high, and sampling the same particles at 200% isokinetic caused the sample concentration to be 50% low.

Vitols developed a theoretical method for determining errors. Using his method he drew graphs showing the effects of anisokinetic sampling. Figures IX-4 is such a graph for 12 micron particles of silicon carbide. The black line is the theoretical curve and the small circles are experimental data. The experimental errors are always slightly less than the theoretical errors. This is probably caused by (1) turbulence, (2) the effect of wall thickness of the sampling nozzle and (3) deviation of the particles from the aerodynamic behavior of spherical particles.

Care should be exercised when reviewing the literature on errors not to confuse particulate mass flow rate with concentration. Since for our tests process weight is calculated from concentration, only errors in concentration should be considered.
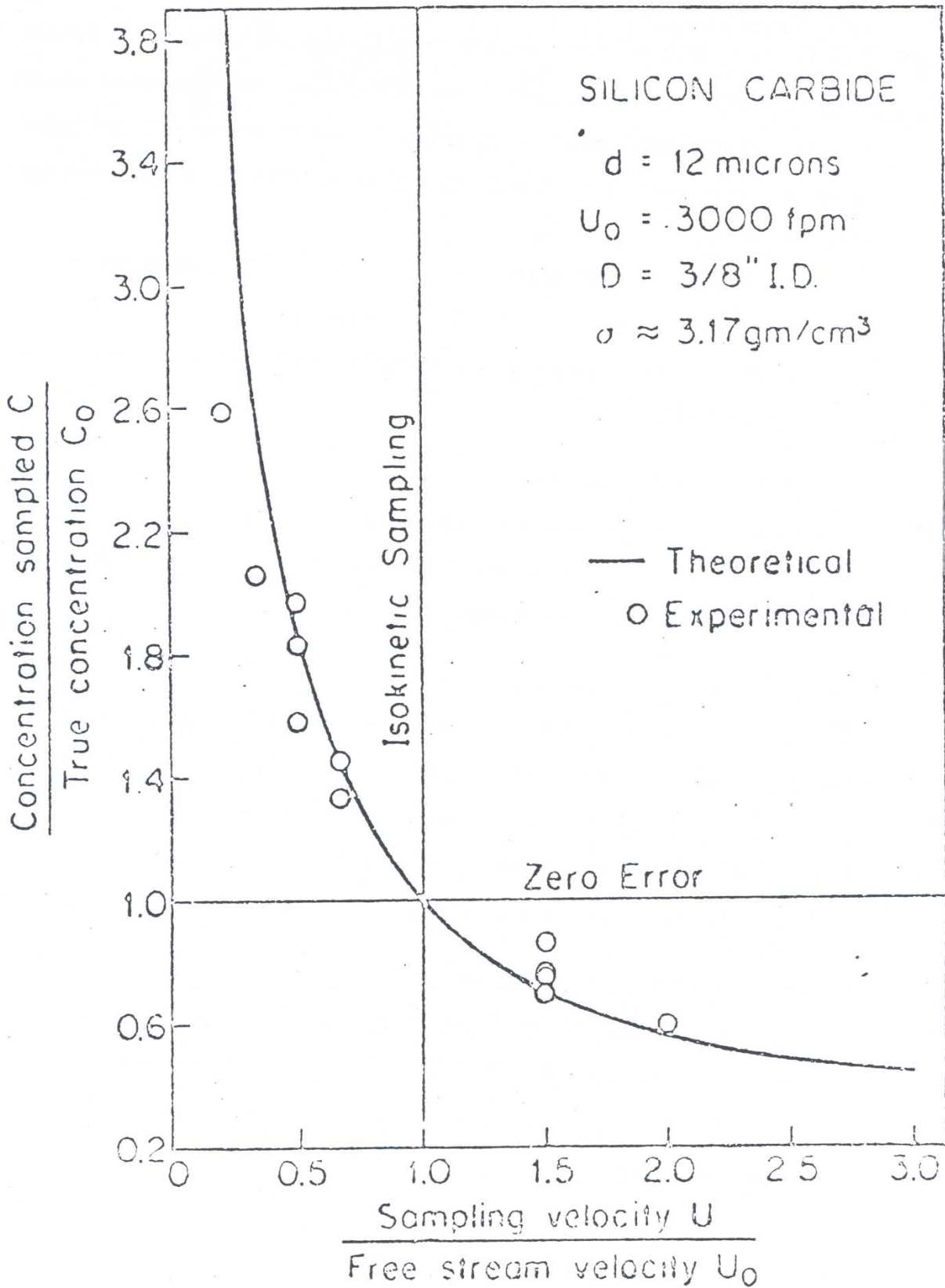
FIGURE IX-4: ANISOKINETIC SAMPLING ERRORS

6.   NOZZLE MISALIGNMENT ERRORS

Misalignment of the sampling nozzle with the streamlines will cause an error. A graph of the error is shown in Figure IX-5. Note that the error is small for misalignment below an angle of ten degrees.

7.   ERRORS CAUSED BY A SMALL NOZZLE

An error in concentration will occur if the sampling nozzle has an inside diameter of less than one-quarter inch (about 0.64 centimeters). The magnitude of this error is shown in Figure IX-6. For high velocities it is better to increase the sampling rate rather than use a small nozzle. If a small nozzle must be used, then the results should be compared with the possible error.

8.   ERRORS CAUSED BY SAMPLING AT ONE POINT

An error may occur if the sample is only taken from one point in the stack. Experiments have shown that the concentration varies about 20% across the stack. Therefore, the stack must be traversed in order to assure the correct average concentration.

9.   SUMMARY

1.   If particulate sampling is not isokinetic, the sampled concentration will be in error.

2.   If the isokinetic ratio is above 100% then the measured concentration will have an error on the low side.

3.   If the isokinetic ratio is below 100% then the measured concentration will have an error on the high side.

4.   The error in concentration caused by anisokinetic sampling will be higher for large diameter particles than for small particles.

5.   Misalignment of the sampling nozzle will cause errors.

6.   Nozzle diameter less than ¼ inch will cause errors.

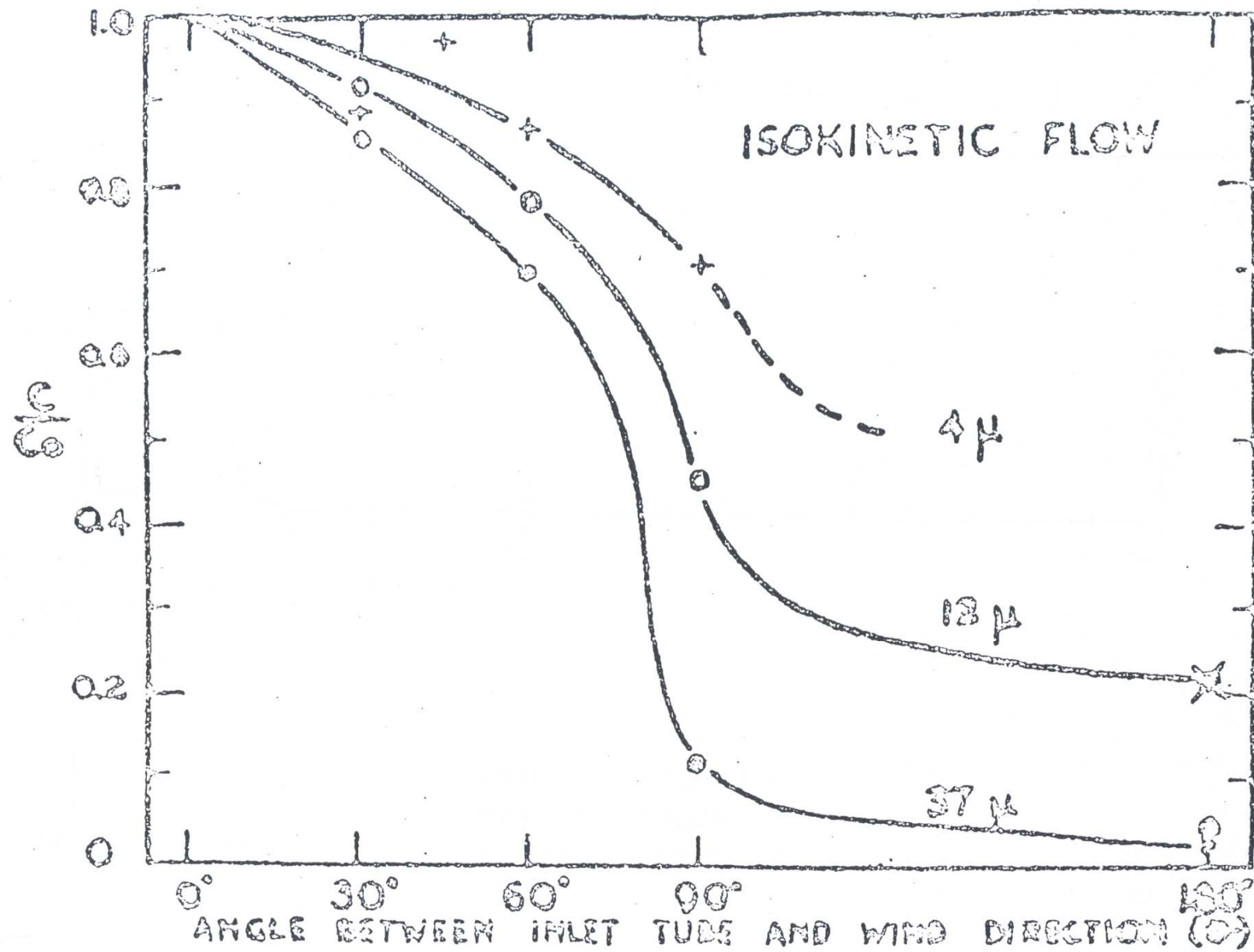7.   Sampling at only one point in the stack may cause errors.

FIGURE IX-5: NOZZLE MISALIGNMENT ERRORS
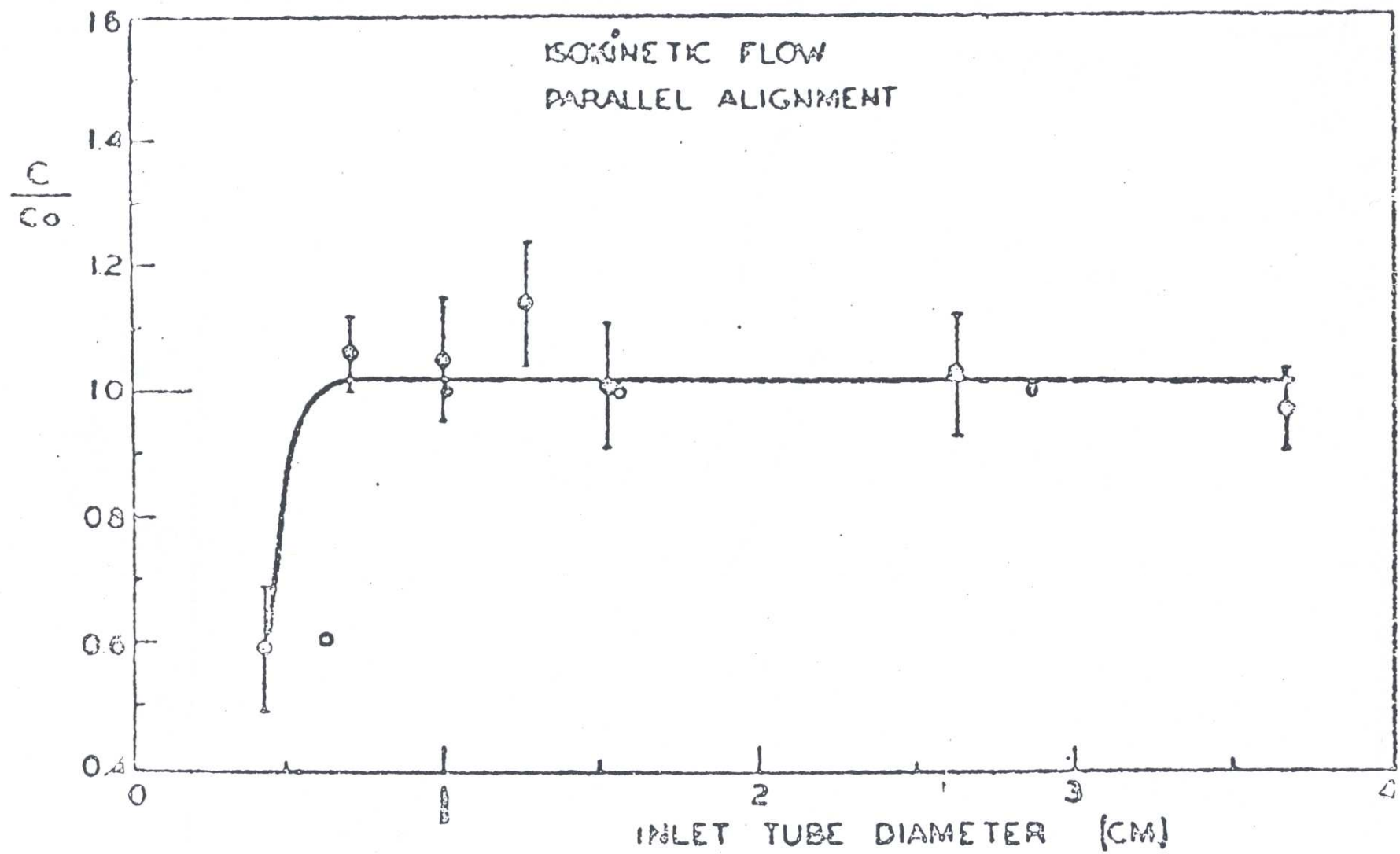
FIGURE IX-6: SMALL TUBE DIAMETER ERRORS

CHAPTER X

DOCUMENTATION, VALIDITY, AND INTERPRETATION
OF TEST RESULTS

1.   INTRODUCTION

APCD personnel should bear in mind that the source testing they perform will
mostly be for the purpose of determining compliance with APCD emissions
regulations. Therefore, source test results form the basis for APCD permit and
enforcement actions, including the granting, denial or revocation of permits-to-
operate. The validity of the source test may likely be an important consideration
in hearing board or court actions.

In view of these facts, APCD personnel have the responsibility of ensuring that
each source test is valid and adequately documented, such that source test
results can withstand rigorous questioning.

2.   DOCUMENTATION

Good documentation is dependent on the careful use of good forms.

The ARB test methods all have suggested formats for test data sheets. Prior
chapters of this manual also contain suggested formats. The form used by the
APCD should contain at least the information shown on the data sheets in this
manual.

The field test data should be entered on the forms in as neat and legible manner
as possible. Sometimes water and dirt droplets from the stack plume will dirty
and smudge the test data sheets. However, do not discard these sheets. They
must be retained and used in evidence as the original sheets.

The laboratory which performs the analysis of the samples should also design
forms on which to report the analyses. These reports form a part of the
documentation and should be retained in the file.

The calculations should be performed and reported in such a manner that it is
easy for another knowledgeable person to check them. A calculator can be
programmed for some of these calculations.

The test data should be summarized on a "Summary of Test Data" sheet, as is
shown in Appendix X-1. This summary makes it easier to perform the
calculations.

The results should be summarized on a form entitled, "Summary of Test Results." The form used by the ARB staff is shown in Appendix X-2. The results of two or more test runs should be averaged and reported in the "average" column.

Ideally, the test results are reported in a "Source Test Report" which relates all of the pertinent facts of the source test.

3.   VALIDITY

The validity of the source test is proven by the documentation of the test.

If the test was conducted according to the practices set forth in this manual, and the instrument readings during the test were made with reasonable accuracy, then the results will have a maximum error of plus or minus 10 percent. Errors in sampling have been previously discussed.

If the test was not conducted according to good practice, then the results will be questionable and difficult to support in a court or hearing board action.

4.   INTERPRETATION OF THE TEST RESULTS

If the test has been properly conducted then the test results for particulate matter are valid within plus or minus 10 percent. If the test results for particulate matter show a concentration of 0.11 grains per standard cubic foot, then the actual concentration could be as low as 0.10 grains per standard cubic foot or as high as 0.12 grains per standard cubic foot. Likewise, if the results show a concentration of 0.12 grains per standard cubic foot, then the actual could be as low as 0.11 grains per standard cubic foot or as high as 0.13 grains per standard cubic foot.

If a particulate matter test was conducted with an isokinetic ratio outside of the range 90 to 110%, then the results are not acceptable under the ARB method. However, the isokinetic ratio might be useful in making a decision as to whether or not a retest is advisable. If the isokinetic ratio was greater than 110% and the calculated concentration exceeded the allowable, then a retest within the acceptable isokinetic ratio and with the same plant operating conditions would show that the concentration exceeds the allowable by an even greater margin. One should also take into account any other factor contributing to the overall accuracy of the test in making a decision as to whether or not a retest is advisable.

If the isokinetic ratio was less than 90%, the reported concentration was higher than the actual. If the reported concentration complies with the rules, then a retest within the acceptable isokinetic ratio and with the same plant operating conditions would show even better compliance. If the reported concentration is

greater than the allowable, then a judgement must be made as to whether or not a retest is advisable based on the degree of noncompliance.

Test results for gaseous samples can also have an error of up to plus or minus 10%. No consideration other than this governs the validity of these results, if the sampling and analysis were properly conducted.

APPENDIX X

TABLE OF CONTENTS

APPENDIX X-1

State of California
AIR RESOURCES BOARD
Division of Implementation and Enforcement
Engineering Evaluation Unit

File No._____

SUMMARY OF TEST DATA

Sampling Station: _____

Material Collected: _____

	Test # 1	Test #2	Test #3
1. P_{bar}, Barometric Pressure, in. Hg			
2. Δh_{avg}, Average Orifice Pressure, in. H_2O			
3. V_m, Sample Gas Volume (Meter Cond.), cu. ft.			
4. T_m, Average Meter Temperature, °F			
5. V_{wc}, Condensed Water Vapor, ml.			
6. T_i, Average Impinger Temperature, °F			
7. T_s, Average Stack Temperature, °F			
8. Stack Gas Analysis (Dry Basis)			
%CO_2			
%O_2			
%CO			
9. $\left(\sqrt{\Delta P}\right)$ Average (in. H_2O)$^{1/2}$			
10. D_s, Stack Diameter, in.			
11. θ_m, Sampling Time, min.			
12. D_n, Sampling Nozzle Diameter, in.			
13. M_n, Sample Weight Collected, mg.			
A.			
B.			
C.			
D.			
Total Weight, mg.			
14. C_p, Pitot Tube Coefficient			
15. P_s, Stack Pressure (absolute) in.Hg			
16. T_a, Ambient Temperature, °F			

17. Additional Data _____

_____

_____

File No._____

State of California
AIR RESOURCES BOARD
Division of Implementation & Enforcement – Engineering Evaluation Unit

SUMMARY OF TEST RESULTS

NAME OF FILM: _____

LOCATION: _____

DESCRIPTION OF OPERATION: _____

STANDARD CONDITIONS: _____

ITEM TESTED: _____

	Rule No.	Measured Emissions			Average	Allowable Emissions
Test No.						
Date of Test						
Duration of Test, minutes						
Process Weight Rate, lbs/hr						
Gas Flow Rate, SCFM (DRY)						
Stack Gas Temp., °F						
CO_2 % by Vol.						
O_2 % by Vol.						
CO% by Vol.						
H_2O % by Vol.						
Particulate Concentration, gr/scf						
Particulate Weight, lbs/hr						
Combustion Contaminants, gr/scf						

COMMENTS: _____

_____

Project Engineer: _____ Checked by: _____

APPENDIX B

LIQUID SAMPLING PROCEDURE

APPENDIX B

LIQUID SAMPLING PROCEDURE

INTRODUCTION

The sampling method described below has been developed for sampling from fixed-roof tanks and/or sample taps located upstream of the tank. It is the authors belief that this procedure, or one essentially equivalent, is necessary to obtain samples for vapor pressure measurements or light end composition (C-1 to C-6 hydrocarbons) analysis. The method is proposed for use in a study of hydrocarbon emissions from fixed-roof tanks in which emissions correlation with the stored liquid vapor pressure is very desirable. However, the basic method should be applicable to many situations which demand collection of a sample without subsequent evaporation loss. All liquid samples should be obtained immediately prior to starting a test, during a test, or immediately after completing a test, whichever is appropriate for the given test conditions. Samples taken at any other time have to be considered as of no use as they cannot be considered to be representative of the tank contents during the test period.

SCOPE

This method is designed to avoid evaporation loss while obtaining, storing, and transporting liquid samples.

A.   PRECAUTIONS

Vapor pressure and the light end composition are extremely sensitive to evaporation losses. Therefore when obtaining, storing, or handling samples great care must be taken to ensure having representative samples. Samples which are to be shipped must conform to all applicable federal, state, and local regulations. When samples are obtained from a sample tap by flowing the product through the sample container all pertinent regulations and precautions against fire, explosion, and other hazards must be observed.

B.   SAMPLING EQUIPMENT (For items 1-5 see Figure 1)

1.   Stainless steel sample cylinders with a minimum volume of 300 cc and having valves (needle or ball with at least a ¼ inch opening) at each end.

2.   Viton "O" ring equipped Circle Seal Check Valve (Cat. No. 249B-6PP) or equivalent.

3.   Seven foot lengths of 3/8 inch O. D. stainless steel tubing.

4.   Fifty foot length of 3/64 inch throttle cable with a 3/16 inch N. C. bolt attached to one end.

5.   ¾ inch pipe plug with a 2 ½ inch long ¼ inch N. C. bolt screwed through it.

6.   Appropriate scale with which to weigh the stainless steel cylinders.

7.   Suitable connections to allow connecting the sample cylinder to a sample tap if one is available.

8.   Wide mouth bottles.

9.   Appropriate sampling apparatus to allow lowering a water filled wide mouth bottle into the tank and inverting it underneath the stock surface.

10.   Appropriate range American Petroleum Institute (API) hydrometers.

C.   <u>PROCEDURE FOR TANKS WITHOUT SAMPLE TAPS</u>

(Refer to Figure 1 for the following instructions.)

1.   Insert a clean, dry pipe plug (E) into a clean, dry relief valve (D) and adjust the bolt in the plug to fit firmly against the relief valve. (See NOTE 1.)

2.   Attach this clean, dry relief valve assembly to a clean, dry, preweighed sample cylinder. Open needle valves (B) and (F) and evacuate the entire assembly by suitable means to 1 mm Hg or less, absolute. Close the needle valves. It is essential to have a high vacuum in the sampling system when a sample is being taken to ensure filling the cylinder liquid full. If the cylinder and check valve assembly have no minor leaks then the system can be evacuated in a laboratory and the vacuum will be maintained for several days. Alternatively one could have a good vacuum pump and a tilting McCloud gauge (to check the vacuum obtained) and do the evacuation in the field immediately prior to sampling.

3.   When ready to obtain a sample remove the pipe plug (E), attach the throttle cable bolt to the relief valve, and attach a clean, dry 3/8 inch O. D. stainless steel tubing to the relief valve assembly. Open valve (F) and submerge the evacuated cylinder 3 to 5 feet (see NOTE 2) below the surface of the liquid then pull the throttle cable to open the relief valve and allow liquid to enter the cylinder. Allow the relief valve to close before removing the filled chamber from the tank. Clean the liquid from the sampling system as it is removed from the tank. Close valve (F) and detach the relief valve assembly. Weigh the sample cylinder and from the liquid weight and the liquid gravity (as supplied by the tank operator or measured on site (see NOTE 2)) calculate the volume of liquid in the cylinder. If the cylinder is less than 95% full then another sample is to be taken.

4. Hold the sample cylinder in a vertical position and open the bottom valve to drain off a small amount of product so that the cylinder meets Department of Transportation regulations for shipment. DO NOT OPEN TOP VALVE OR ALLOW AIR TO ENTER THE SAMPLE CYLINDER.

D. PROCEDURE FOR TANKS WITH SAMPLE TAPS

1. If tank sample taps are available then select the tap which is the closest to being 3 to 5 feet below the liquid surface. (See NOTE 2.) Open this tap and allow liquid to flow through it to a suitable receptacle until the residual tap line liquid is completely flushed out.

2. Connect a clean, dry evacuated sample cylinder to the tap with suitable connections. (See NOTE 1.) The cylinder MUST be connected to the sample tap in such a way that it can be filled from the bottom. In general this will probably require having some clean, dry pipe and elbows available which can be used to enable connecting the tap to the bottom cylinder valve. This precaution ensures that any gas formed by flashing when the liquid enters the evacuated cylinder will subsequently be completely flushed out of the cylinder. It is particularly important to observe this precaution when sampling from a tap where the liquid being sampled is under a positive pressure. Connect a hose to the top cylinder valve to run the excess liquid sample into a suitable receptacle. The sample is then taken by: (a) first opening the tap, (b) second opening the cylinder valve nearest the tap, and (c) third opening the cylinder valve furthest from the tap allowing liquid to flow through the cylinder to the suitable receptacle.

3. When the five liquid volumes have passed through the cylinder isolate the sample by reversing the above operations, i. e. (a) first close the cylinder valve furthest from the tap, (b) second close the valve closest to the tap, and (c) third close the tap valve and then disconnect the cylinder from the tap.

4. Hold the sample cylinder in a vertical position and open the bottom valve to drain off a small amount of product so that the cylinder meets Department of Transportation regulations for shipment. DO NOT OPEN TOP VALVE OR ALLOW AIR TO ENTER THE SAMPLE CYLINDER.

E. PROCEDURE FOR SYSTEMS REQUIRING UPSTREAM SAMPLING

1. If immediately prior to the test tank the liquid product goes through a unit where a pressure reduction occurs then a liquid sample may have to be taken upstream of this unit. Upstream sampling is required for the following three circumstances: (a) the vapors formed in the unit flow

directly into the test tank vapor space, (b) because of the reduced pressure entrained gas enters the test tank with the liquid product, or (c) because of the reduced pressure gas bubbles from the liquid as soon as the liquid enters the test tank.

2. If none of the foregoing three circumstances occur the test tank can be sampled by either of the two methods previously described (C or D).

3. If ANY of the circumstances described in E-1 above is true then the liquid sample MUST be taken from a sample tap UPSTREAM of the unit where the pressure reduction takes place. When a suitable tap has been located the sample can be obtained by the technique given in D above.

NOTE 1:

After each use the sampling apparatus should be thoroughly cleaned with 1,1,1-trichloroethane, or other appropriate solvent, then with a light hydrocarbon solvent. Following the final cleaning the apparatus should be thoroughly dried to remove all traces of the solvent.

The cleaning of the check valve assembly, tap connections, and any part of the apparatus through or over which liquid might pass in going into the sample cylinder is absolutely necessary.

NOTE 2:

Before a liquid sample is taken one should obtain from the tank operator as much information as possible about the tank contents. Of crucial interest is the gravity(ies) of the stock(s) in the tank. Particularly with crude oils it is possible that crudes having more that 2 degrees API gravity difference may be present in the same tank. If this occurs the lighter crude will float on the heavier crude and since evaporation takes place from the surface the liquid sample should consist of only the lighter crude. If the tank operator does not have the appropriate information then liquid samples should be obtained at the following depths below the liquid surface: 1 to 2 inches, 1 foot, 2 foot, 3 foot, and 5 foot. These samples can be taken in wide mouth bottles by the water displacement method. The API gravity of each sample is then determined on site. If there is no appreciable gravity difference then a liquid sample can be taken in a stainless steel cylinder between 3 to 5 feet below the liquid surface. If there is more than 2 degrees API difference in the gravities then the sampling location should be chosen so that the lightest liquid is sampled. The sample can be taken by method D if a sample tap is available at the correct depth, otherwise the sample has to be taken by method C.